SUSY Results from CMS

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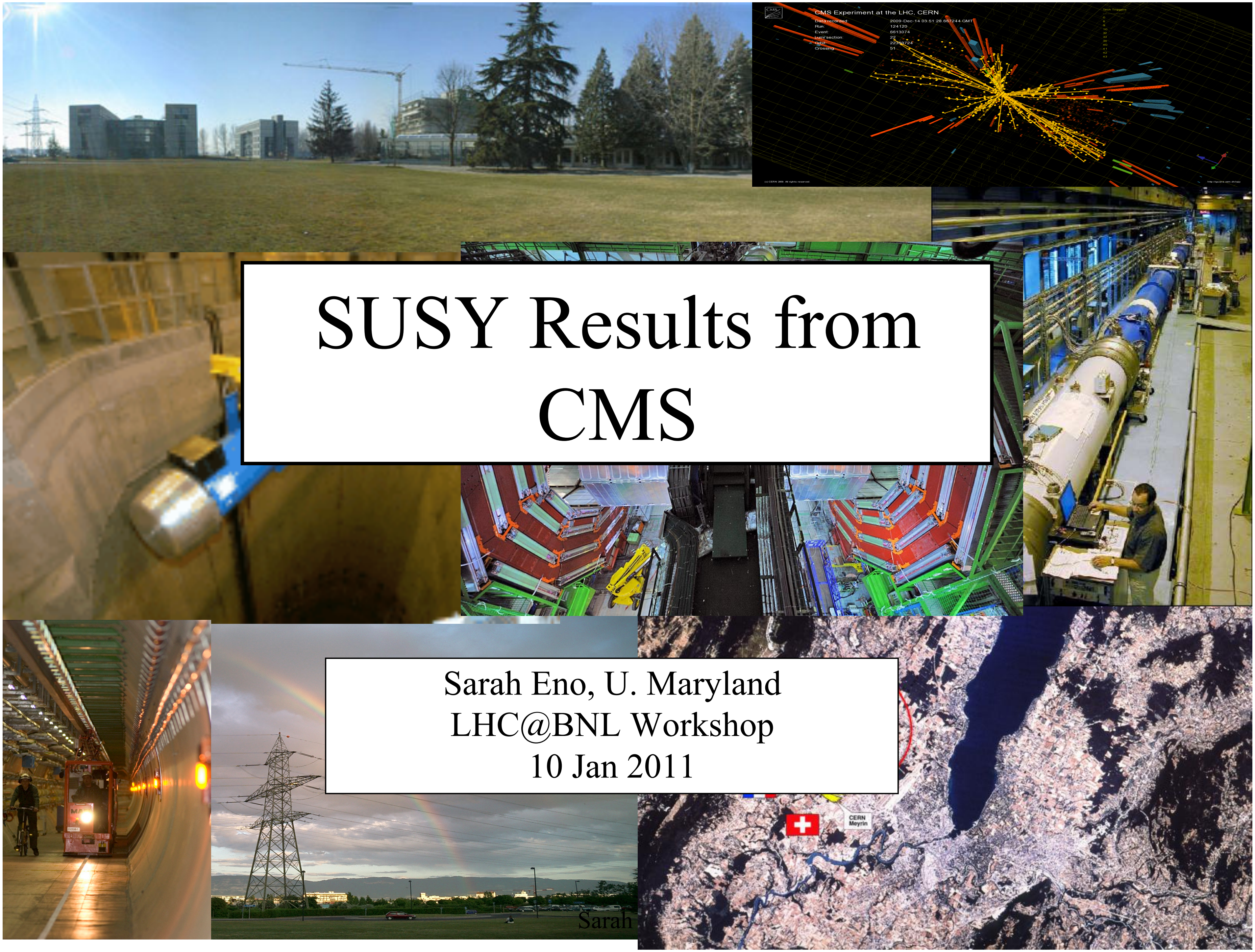
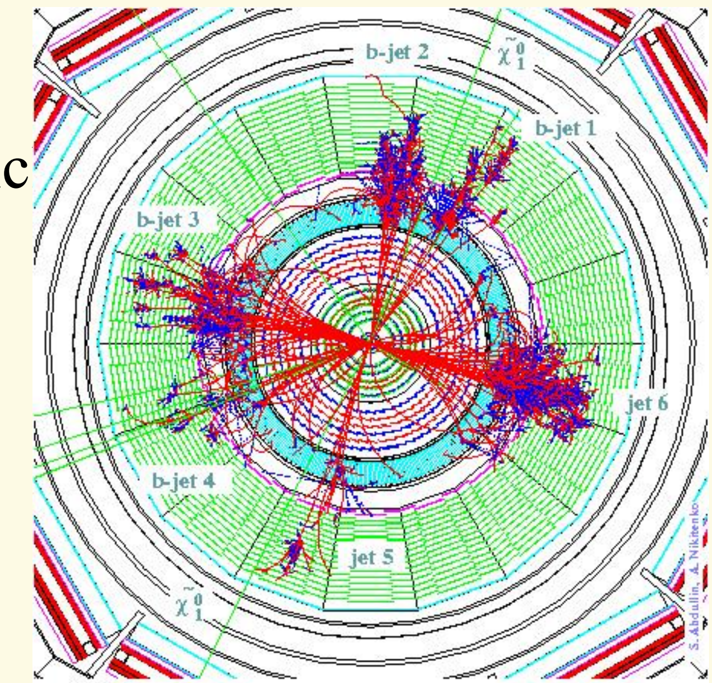
LHC@BNL Workshop
10 Jan 2011

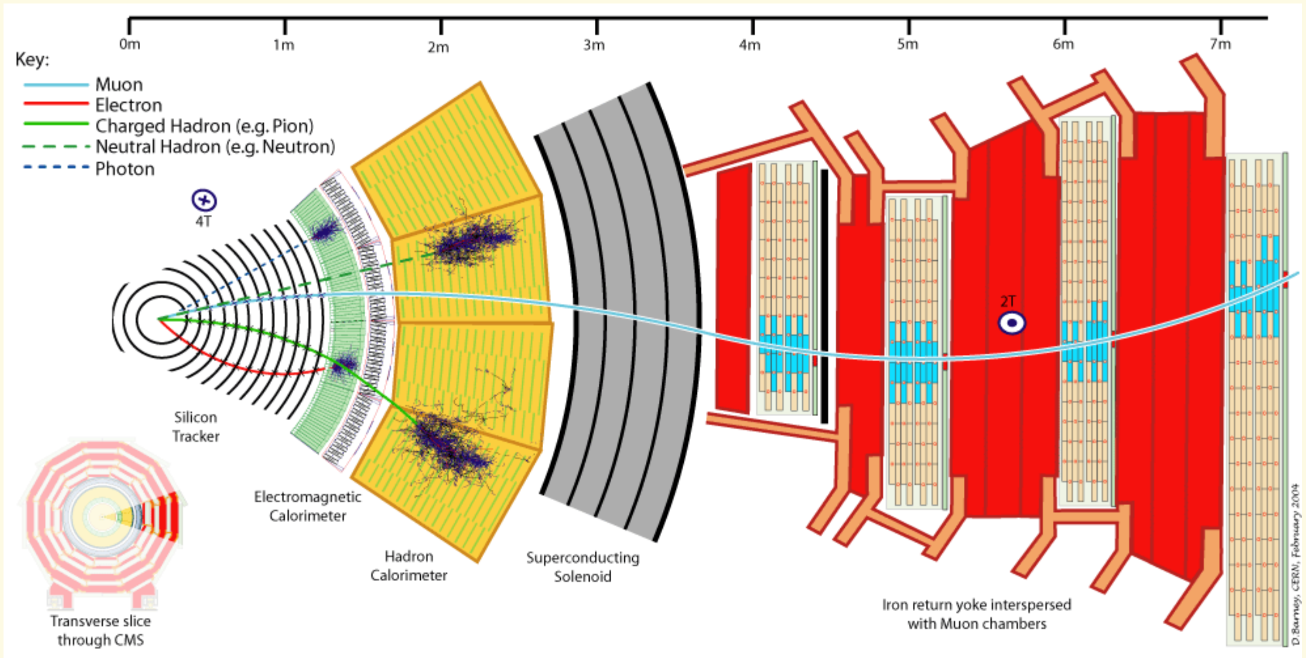


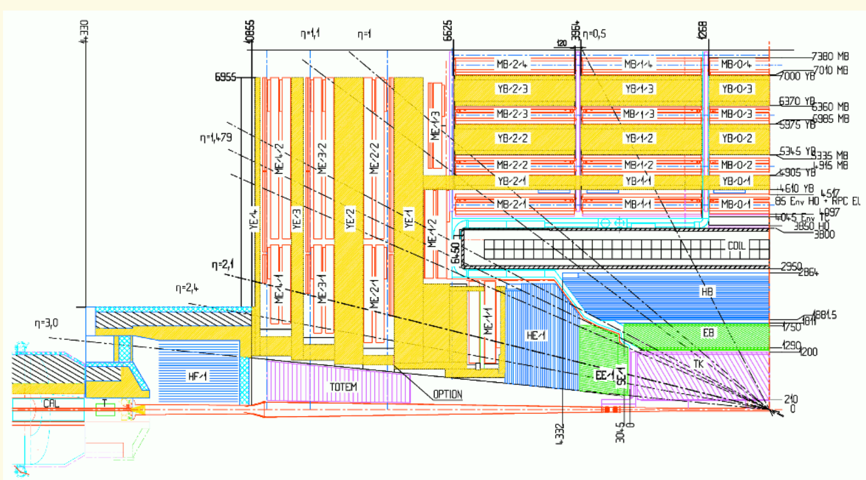
SUSY @ CMS

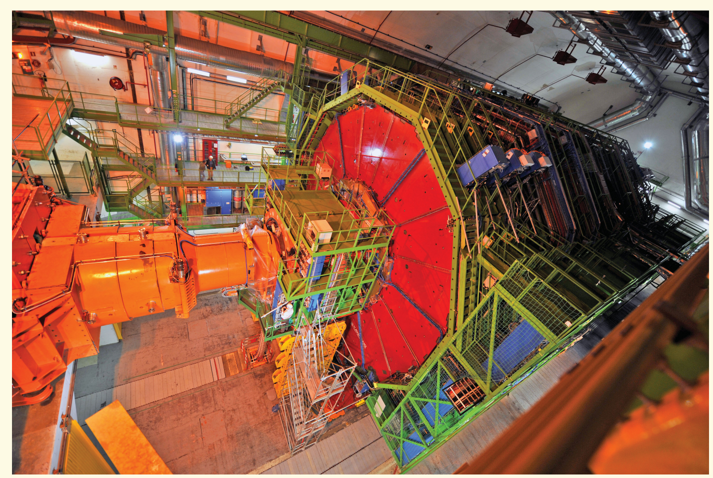
- CMS
- "Classic" SUSY
  - "classic" susy searches
    - α_T NEW!!
- "Exotica" SUSY searches
  - Heavy "Stable" Charged Partic
  - Stopped rhadrons
- Conclusions



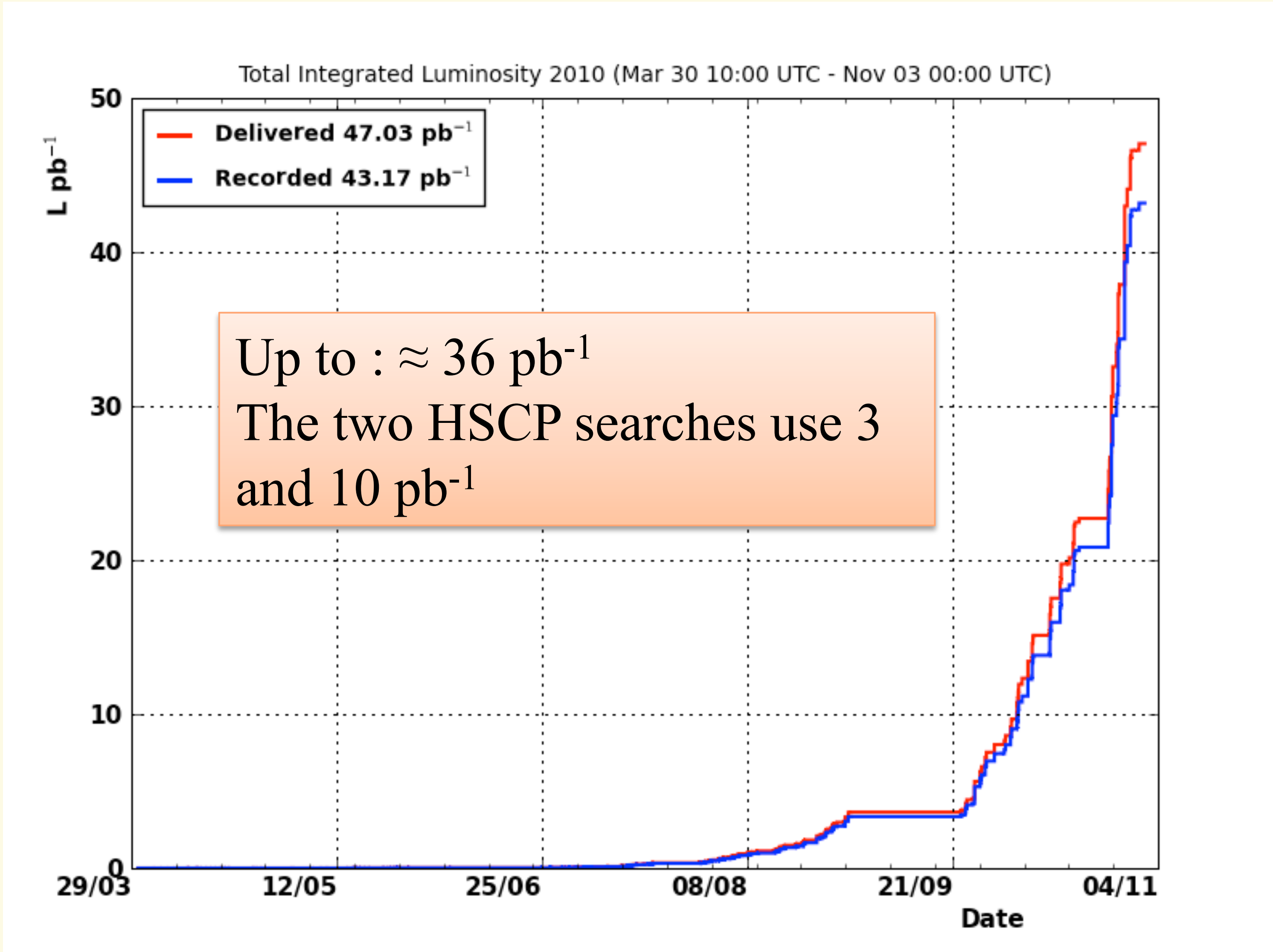
CMS Detector







Integrated Luminosity



Up to : ≈ 36 pb^{-1}

The two HSCP searches use 3 and 10 pb^{-1}

Classic SUSY

Searching for SUSY in all hadronic states: squarks/gluinos to jets and MET

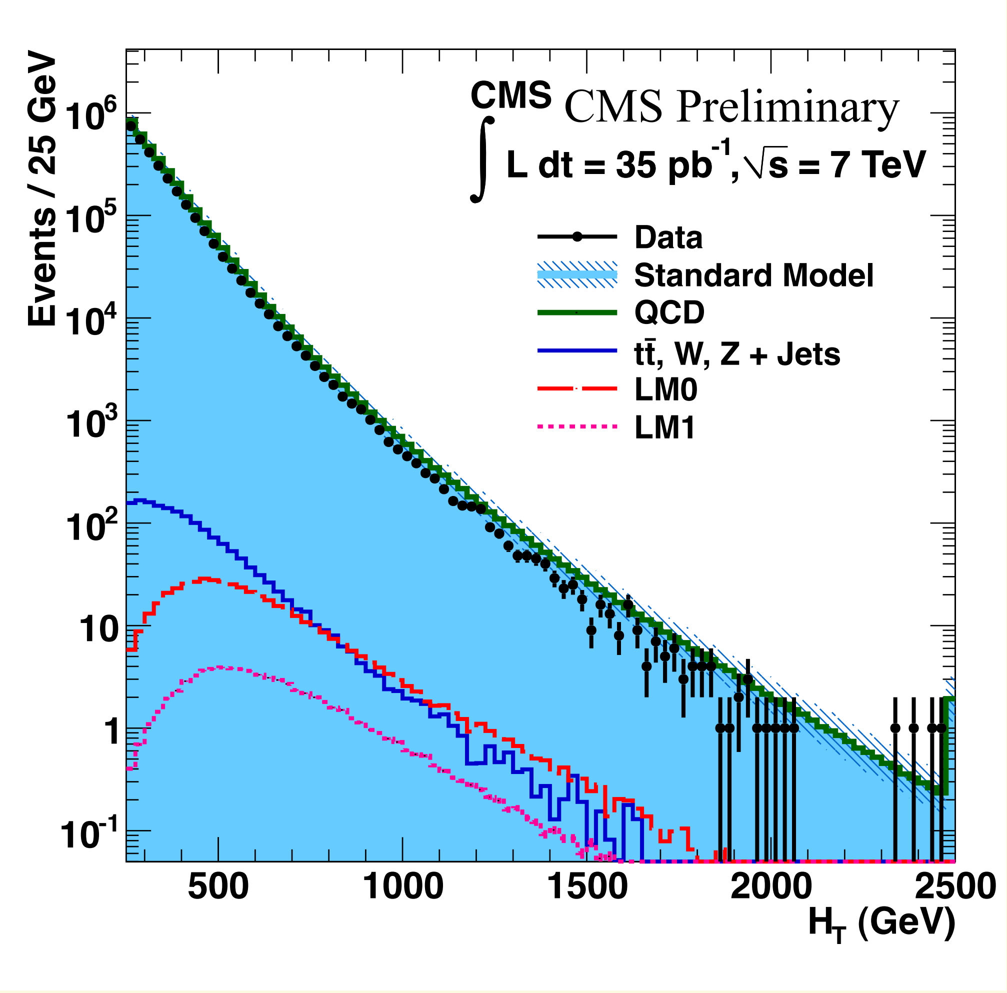
SUSY in Jets and MET

$35\,pb^{-1}$

First steps are easy:

- H_T trigger
- leading jet η< 2.5
- two leading jets have E_T>100
- Veto if isolated muon or electron with PT>10 GeV (W, top veto)
- Veto if isolated photon with P_T>25 (W, top veto)
- H_T> 350 (over all jets with E_T>50, eta<3.)

Still dominated by QCD



QCD is PYTHIA with tune Z2

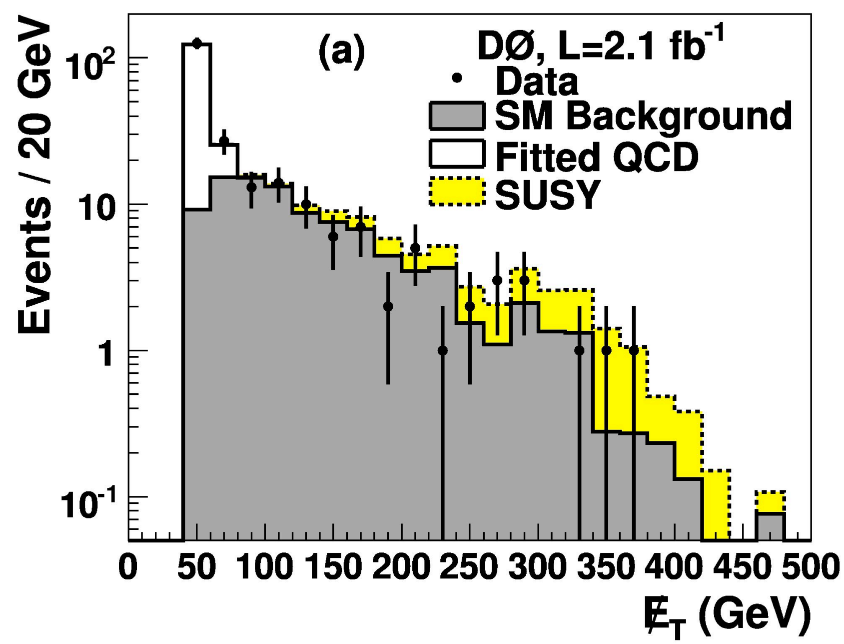
Getting Rid of QCD

Traditional way to get rid of QCD is with cuts on the opening angle in phi between jets and MET

D0 “Two Jet Analysis”

TABLE I: Selection criteria for the three analyses (all energies and momenta in GeV); see the text for further details.

Preselection Cut	All Analyses		
$\not\!\!E_T$	≥ 40		
|Vertex z pos.|	< 60 cm		
Acoplanarity	$< 165°$		
Selection Cut	**“dijet”**	**“3-jets”**	**“gluino”**
Trigger	dijet	multijet	multijet
$\text{jet}_1\ p_T{}^a$	≥ 35	≥ 35	≥ 35
$\text{jet}_2\ p_T{}^a$	≥ 35	≥ 35	≥ 35
$\text{jet}_3\ p_T{}^b$	–	≥ 35	≥ 35
$\text{jet}_4\ p_T{}^b$	–	–	≥ 20
Electron veto	yes	yes	yes
Muon veto	yes	yes	yes
$\Delta\phi(\not\!\!E_T, \text{jet}_1)$	$\geq 90°$	$\geq 90°$	$\geq 90°$
$\Delta\phi(\not\!\!E_T, \text{jet}_2)$	$\geq 50°$	$\geq 50°$	$\geq 50°$
$\Delta\phi_{\min}(\not\!\!E_T, \text{any jet})$	$\geq 40°$	–	–
H_T	≥ 325	≥ 375	≥ 400
$\not\!\!E_T$	≥ 225	≥ 175	≥ 100



Phys. Lett. B 660 , 449 (2008)

α_T: power against QCD

$$\alpha_T = \frac{E_T^{J_2}}{M_T}$$

If there are more than 2 jets > 50 GeV, two pseudo-jets are formed so that the difference in transverse energy between the two pseudo-jets is minimized.

for two jets, $M_T = \sqrt{2E_T^{J1}E_T^{J2}(1-\cos\Delta\phi)}$

$$\alpha_T = \frac{1}{\sqrt{2}}\sqrt{\frac{E_T^2}{E_T^1}}\frac{1}{\sqrt{1-\cos\Delta\phi}}$$

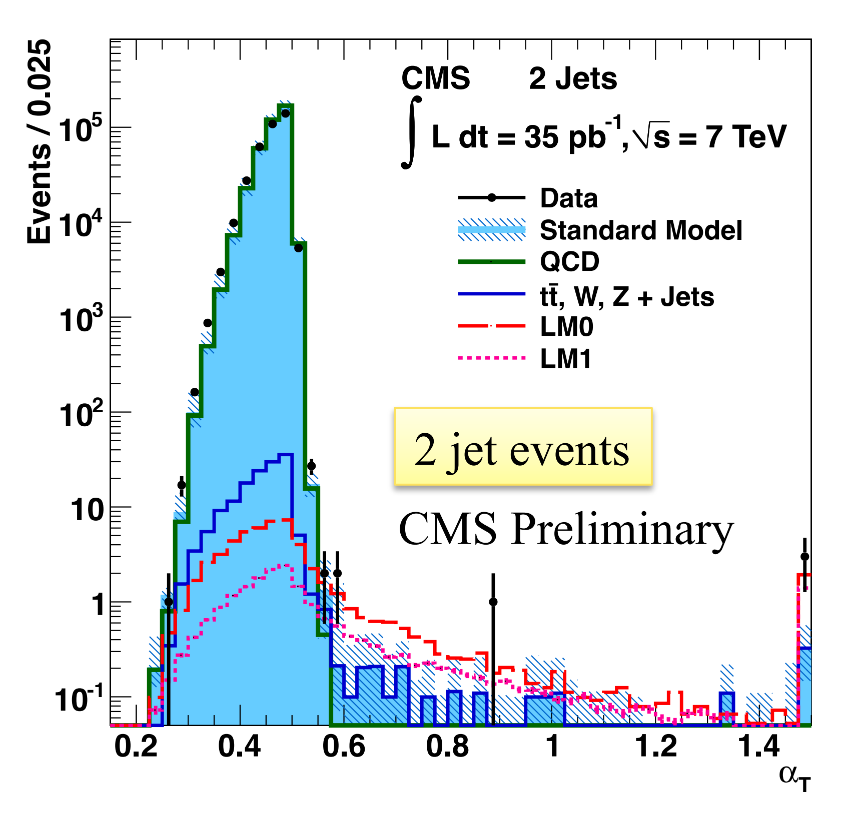
has minimum when $\Delta\varphi$ is π

is infinity when the two jets are parallel.

If jets are back to back $\alpha_T = \frac{1}{2}\sqrt{\frac{E_T^2}{E_T^1}}$

which is clearly <0.5

Allows difficult 2-jet analysis



QCD background rejection

α_T>0.55 leaves:

- real met (W, top, Z➔νν,b's)
- jets below the 50 GeV threshold
- severe jet mis-measurement or multiple jet mis-measurement

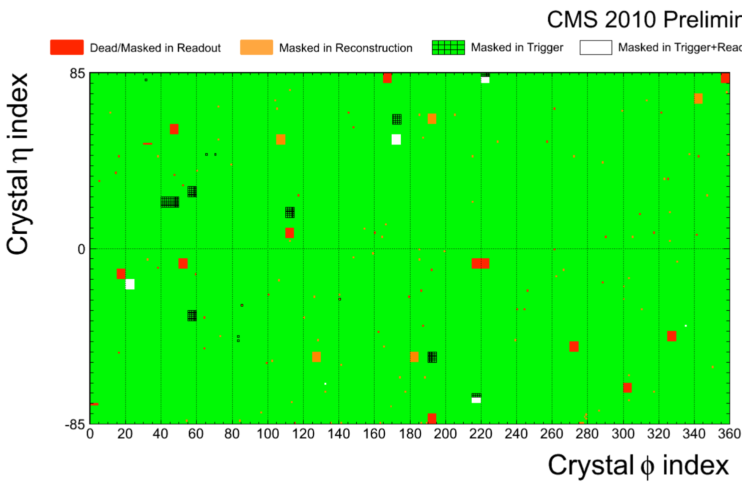
Get rid of second category by requiring consistency between MET and MHT (a pseudo-MET calculated from the jets included in the HT calculation)

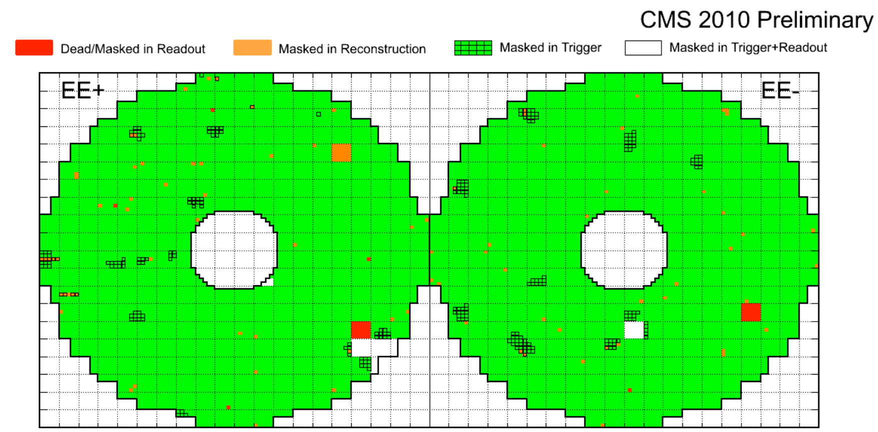
$$\frac{\not{H}_T}{\not{E}_T} < 1.25$$

Get rid of third category by…

ECAL Dead FED

EGM-10-002





101/75848 (0.1%) channels have broken readout.
Want to eliminate events with jet pointing to dead region.
Find jet best matched in φ to MET.
$\Delta\varphi^*$ is $\Delta\varphi$ between the center of the jet and MET.
If $\Delta\varphi^*<0.5$, event is rejected if jet is within $\Delta R=0.3$ of a dead channel.

Data

After these selection, remaining events dominated by final states containing real MET.

(especially $Z \rightarrow \upsilon\upsilon$ and events containing $W \rightarrow \tau\nu$)

Selection	Data	SM	QCD multijet	$Z \to \nu\bar{\nu}$	$W + \text{jets}$	$t\bar{t}$
$H_T > 250\,\text{GeV}$	4.68M	5.81M	5.81M	290	2.0k	2.5k
$E_T^{j2} > 100\,\text{GeV}$	2.89M	3.40M	3.40M	160	610	830
$H_T > 350\,\text{GeV}$	908k	1.11M	1.11M	80	280	650
$\alpha_T > 0.55$	37	30.5±4.7	19.5±4.6	4.2±0.6	3.9±0.7	2.8±0.1
$\Delta R_{ECAL} > 0.3 \vee \Delta\phi^* > 0.5$	32	24.5±4.2	14.3±4.1	4.2±0.6	3.6±0.6	2.4±0.1
$R_{miss} < 1.25$	13	9.3±0.9	0.03±0.02	4.1±0.6	3.3±0.6	1.8±0.1

MC background estimation.

There are also several data-driven methods.

QCD prediction after cuts from PYTHIA and MADGRAPH agree.

All backgrounds

Look at events passing:

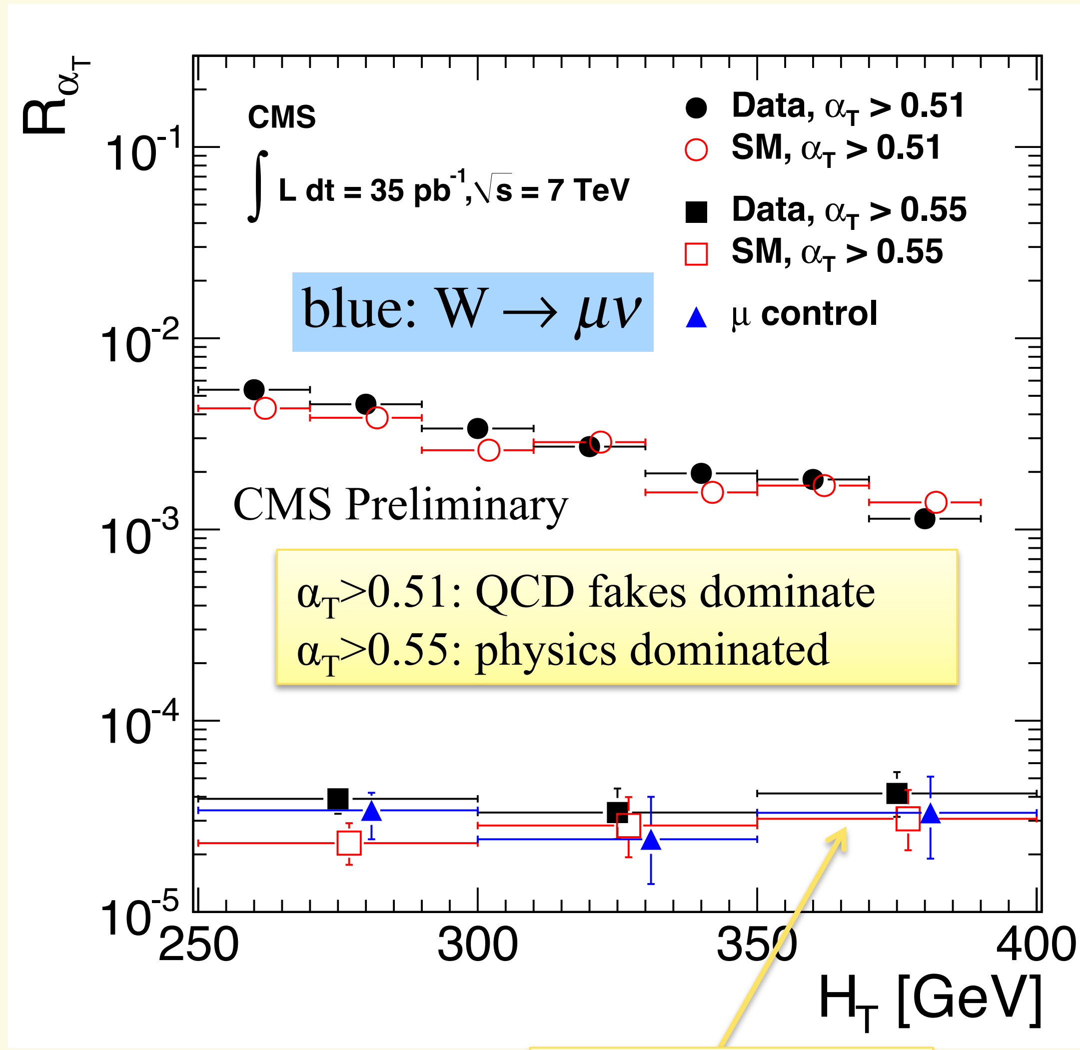
- leading jet $\eta < 2.5$
- H_T (from jets with $E_T > H_T/7$)
- Two leading jets $E_T > H_T/3.5$
- veto if has isolated γ,e,μ

Take ratio of pass/fail rate for

- $\alpha_T > 0.55$
- not near dead ecal fed
- MHT/MET<1.25

predicts $9.4 \pm^{4.8}_{4.0} \pm 1.0$

MC method predicted 9.26 ± 0.9



Signal Region

Individual backgrounds

W+jets and $t\bar{t}$

Select $W \to \mu\nu$ ($P_T^W > 30$ GeV, $M_T > 30$ GeV, $\not{H}_T > 140$ GeV)

25 observed with 29.4 ± 1.4 predicted

require $\alpha_T > 0.55$

7 observed, 5.9 predicted

scale by ration of τ to μ acceptance

$6.1^{+2.8}_{-1.9}(stat) \pm 1.8(syst)$

$Z \to \upsilon\upsilon$ estimated in a similar manner

from direct γ sample and also from $W \to \mu\nu$:

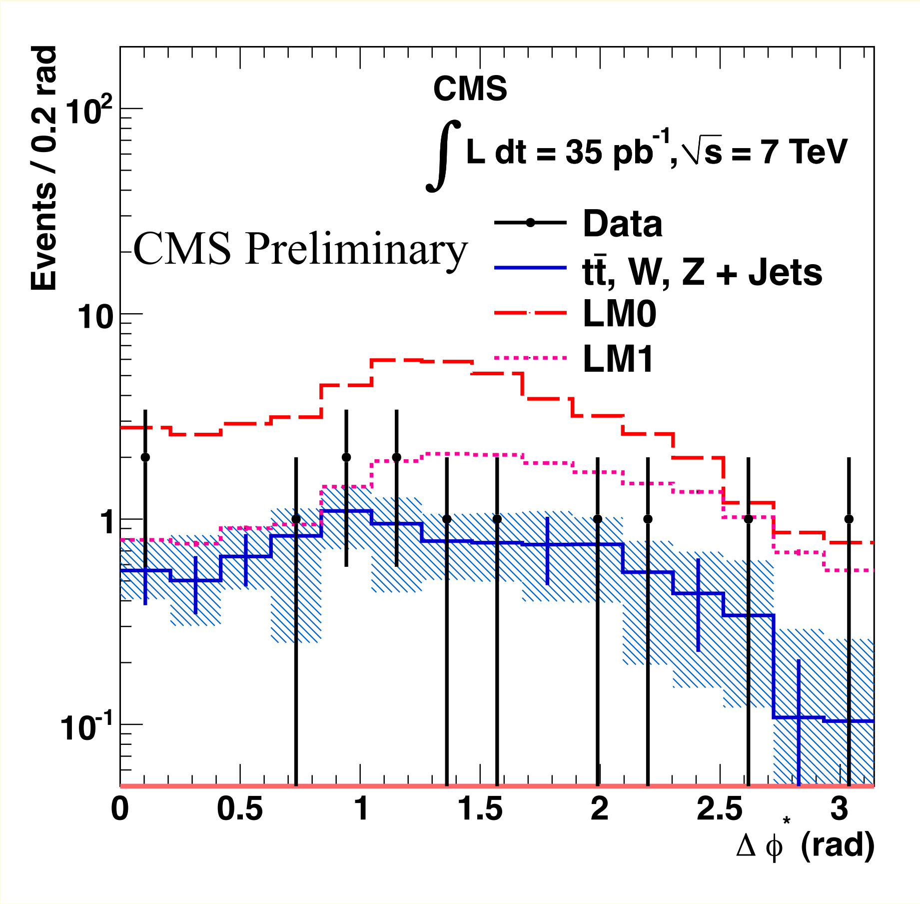
$4.4^{+2.3}_{-1.6}(stat) \pm 1.5(syst)$

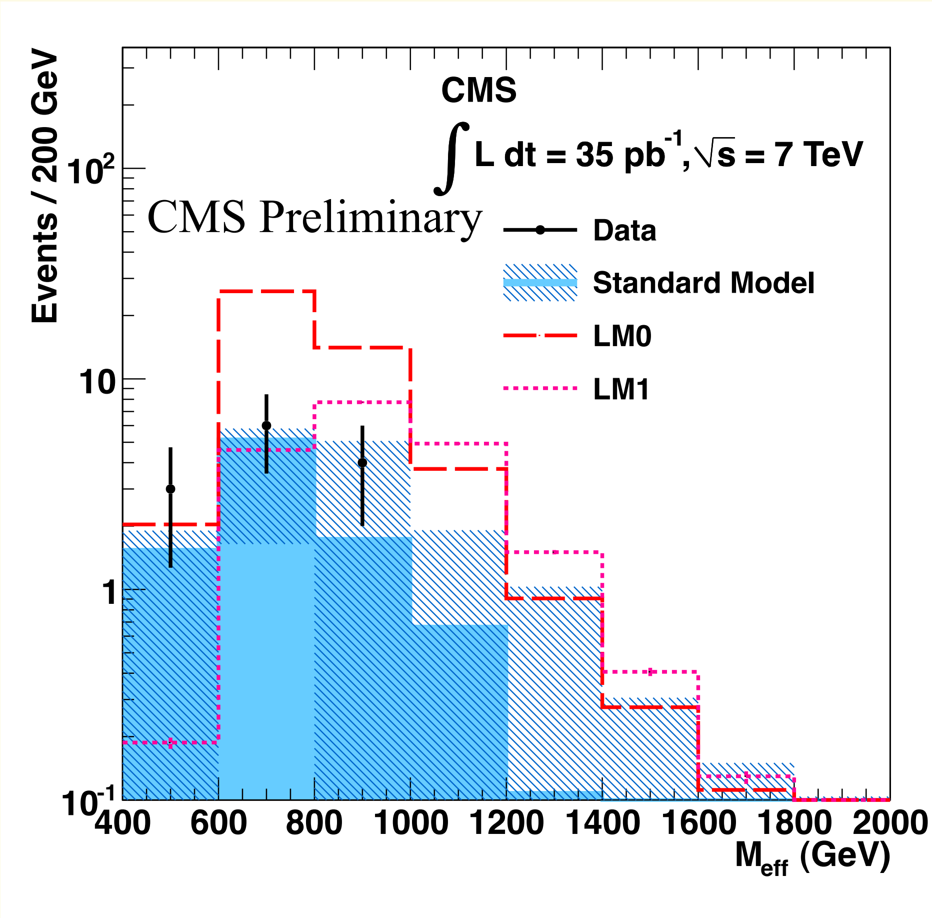
MC method: 9.26 ± 0.9

efficiency method: $9.4^{+4.8}_{-4.0} \pm 1.0$

dead reckoning: $10.5^{+3.6}_{-2.5}$

Distributions for Final Sample

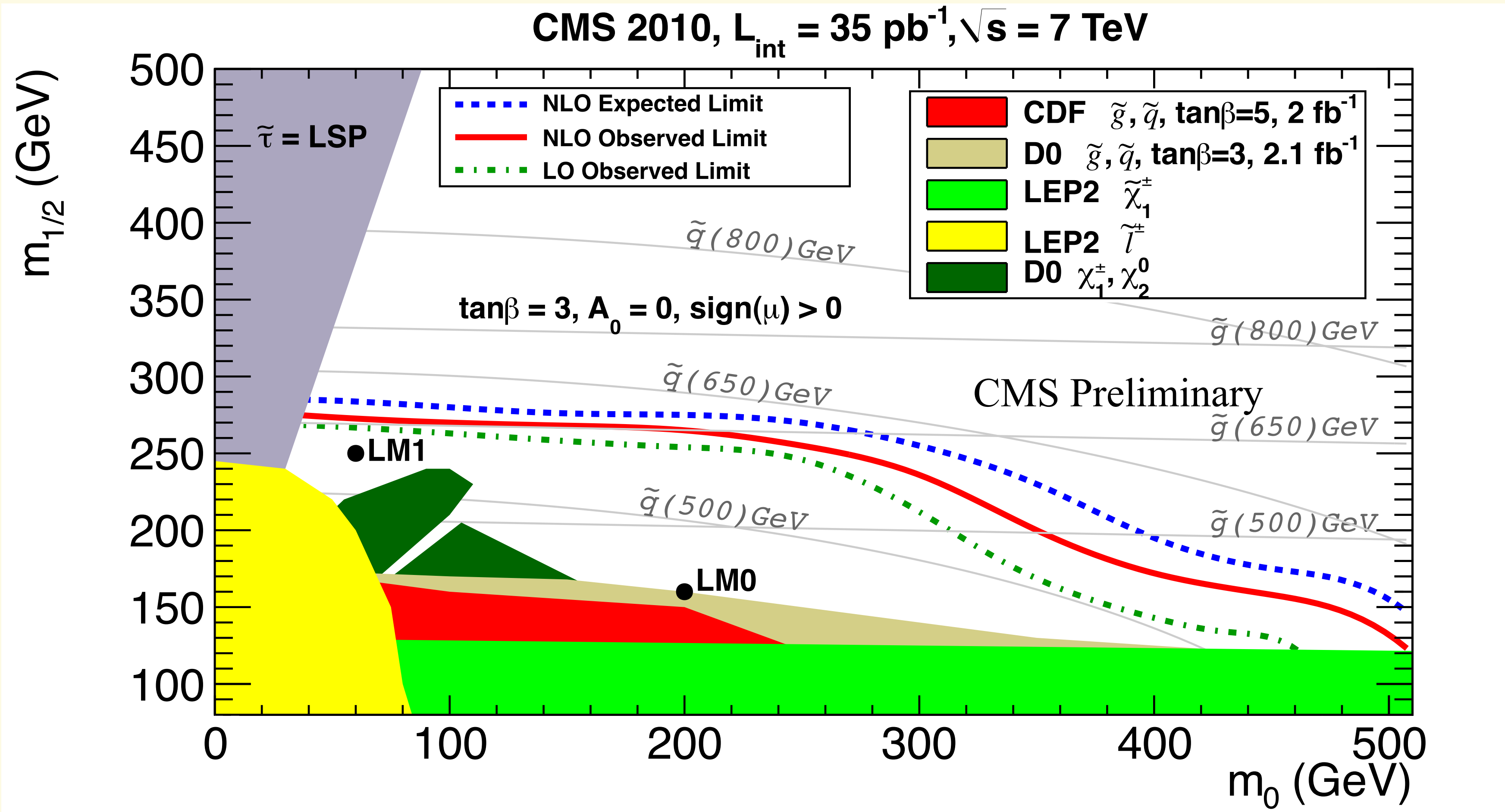




$$M_{eff} = H_T + \not{H}_T$$

Final 13 events

Limit on CMSSM



Exotic SUSY Searches

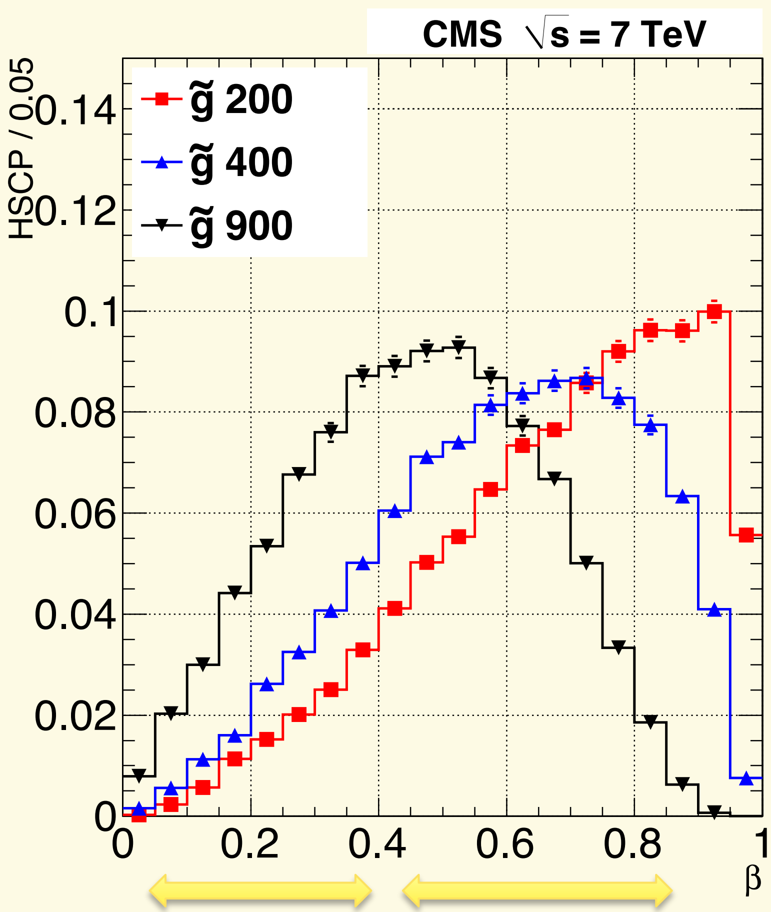
Heavy "stable" charged particles

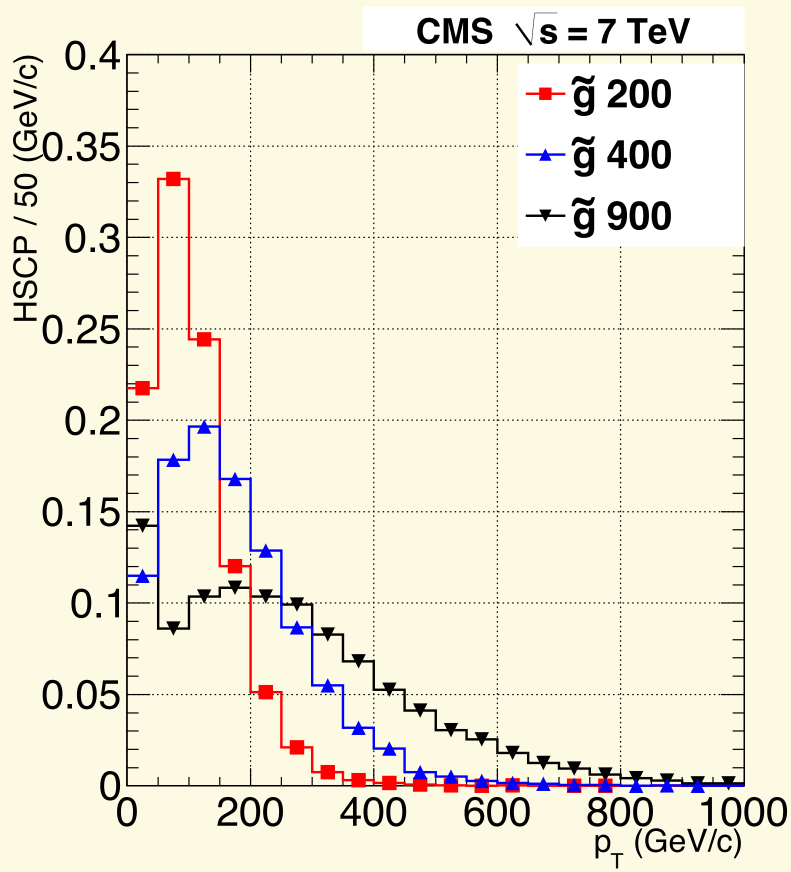
HSCP arise in models with new state and new conserved (or almost conserved) global quantum number, i.e. SUSY with R-parity of ED with KK-parity. The particle is either the LSP or an NSLP with a very long life time due to small coupling or close mass splitting.

Some SUSY examples:

- Gauge Mediated Supersymmetry Breaking SUSY has long lived stau NLSP with gravitino LSP. Generally produced from decays of squarks and gluions.
- Minimal Supersymmetric Standard Model with light stop as NLSP and small mass splitting between stop and LSP
- split SUSY (all scalar particles have high mass). Long-lived gluino (R-hadron)

Gluino p_T and β distributions

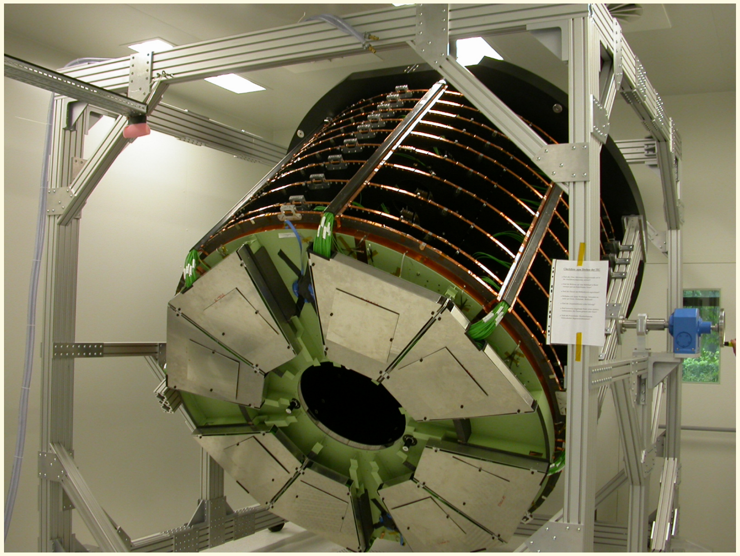


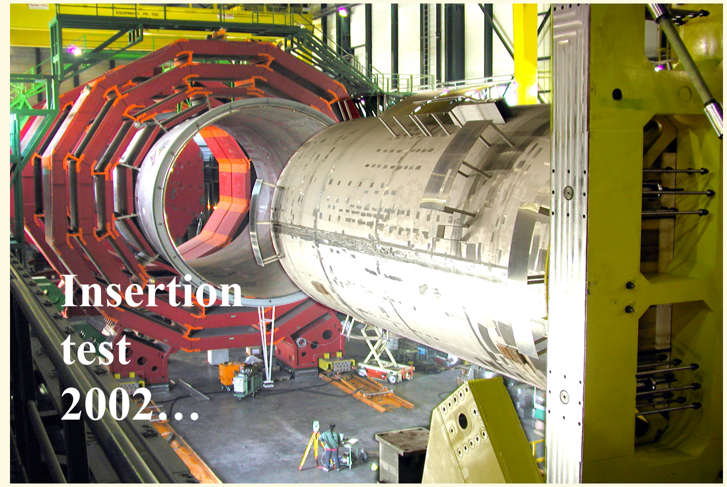


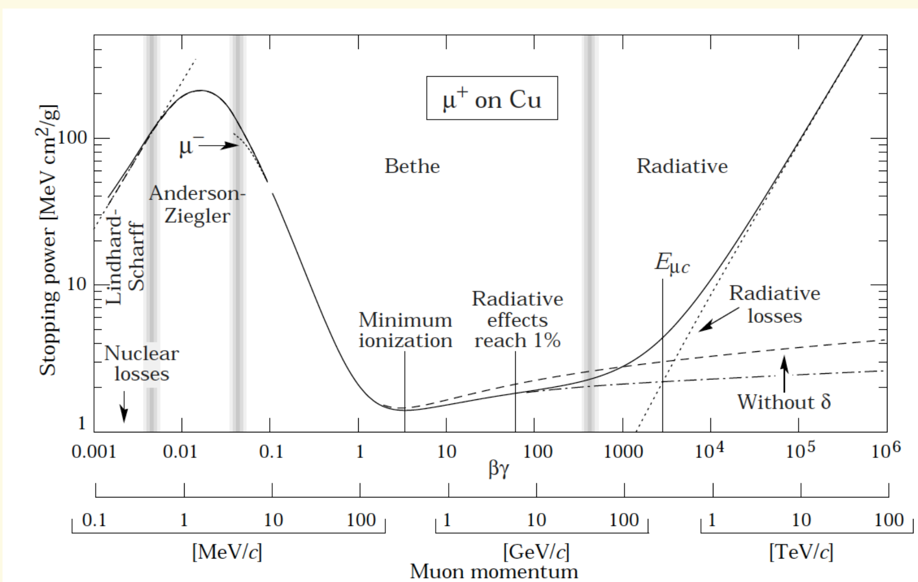
Look for particles with moderate β (0.4<β<0.9) using HSCP analysis.

Look for heavy particles at low β (<0.4) using stopped rhadron analysis.

Heavy "Stable" Charged Particles







Strategy: Look at high p_T tracks in events taken off a variety of triggers (muon, MET, jet).

Use momentum measurement from tracker and magnet with β from dE/dx in silicon strip trackers to search for heavy stable charged particles in $3.06 \pm 0.34\ pb^{-1}$ (update from 194 nb^{-1} result at ICHEP)

HSCP Selection

Triggers: muon, $P_T > 9$ GeV or dimuons, $P_T > 3$ GeV or MET>100 GeV or jet, $E_T > 100$ GeV

Tracker-only analysis

$3.06 \pm 0.34\ \text{pb}^{-1}$

track with high dE/dx (from I_{as}) and

high P_T (> 15 GeV with ≥ 3 silicon strip hits, preselection, with final selection based on number of hits,)

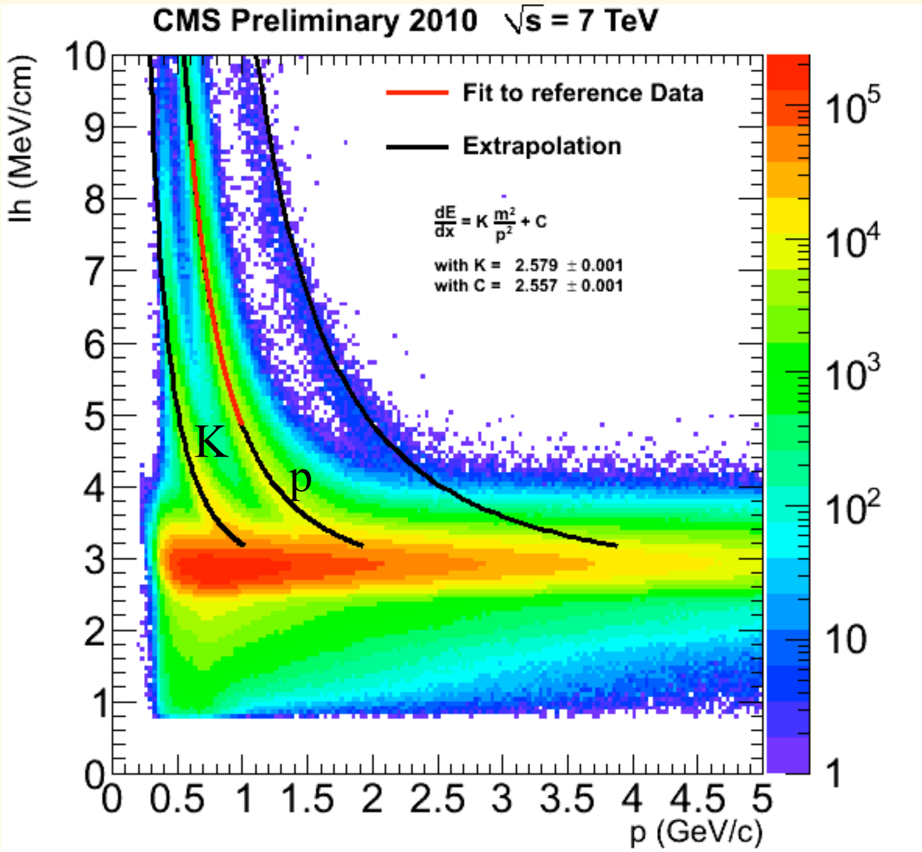
Tracker-plus-muon analysis

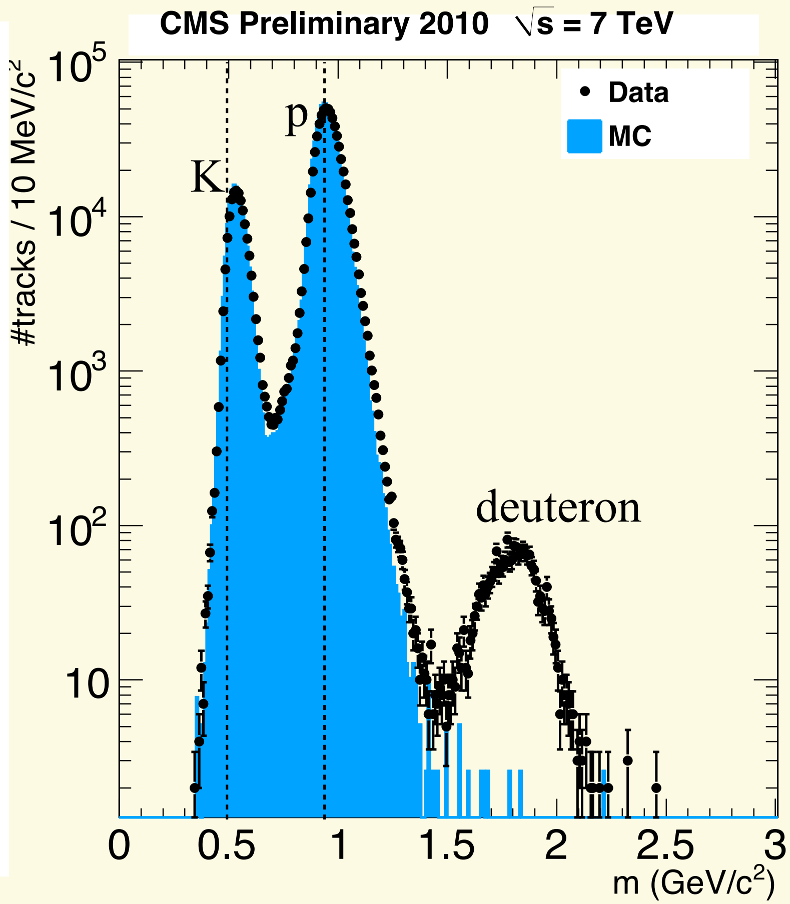
as above, but also matched to a muon-system track

muon trigger only efficiency for β>0.5. Only fully efficient at 0.7

Both loose and tight selections are defined to allow testing of background prediction.

dE/dx and mass





$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{-1/2}$$

c_i is charge/path length

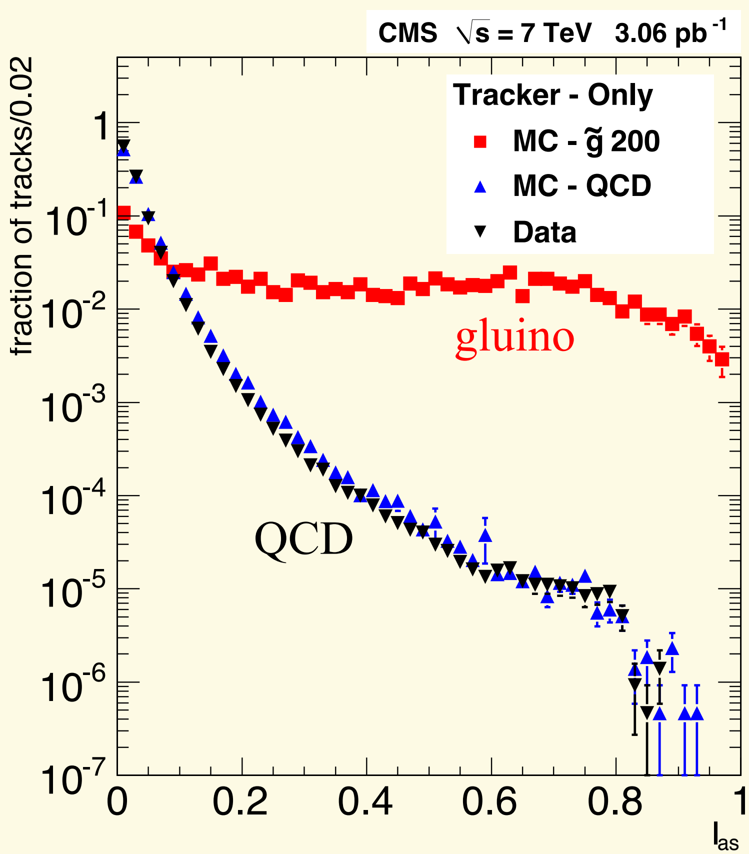
$$I_h = K\frac{m^2}{p^2} + C$$

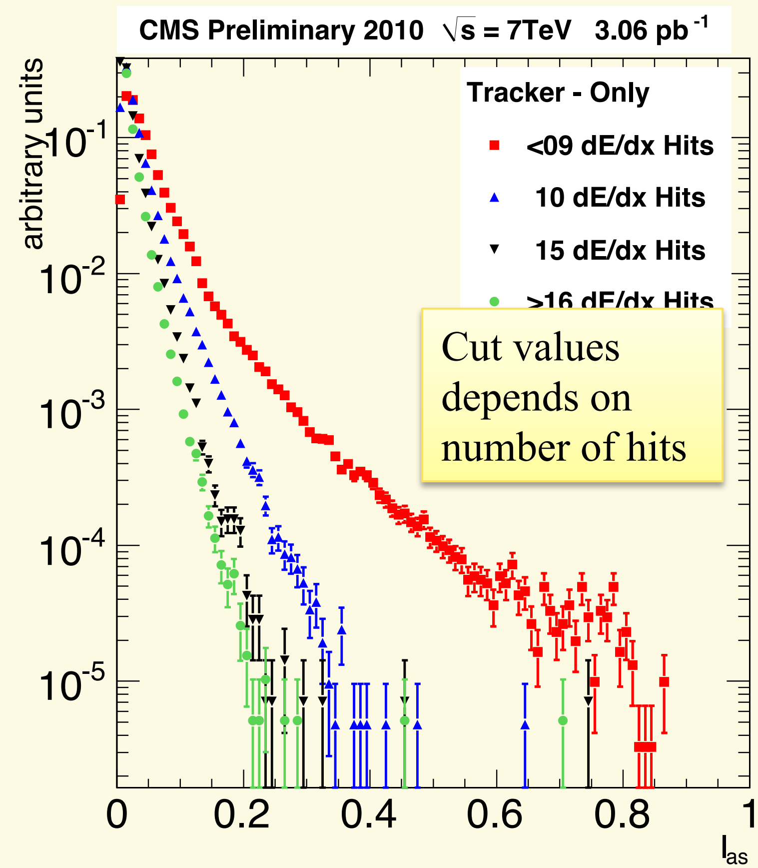
Additional Discrimination

Modified Smirnov Cramer-von Mises discriminate

$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N \text{ Silicon strip hits}} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right)$$

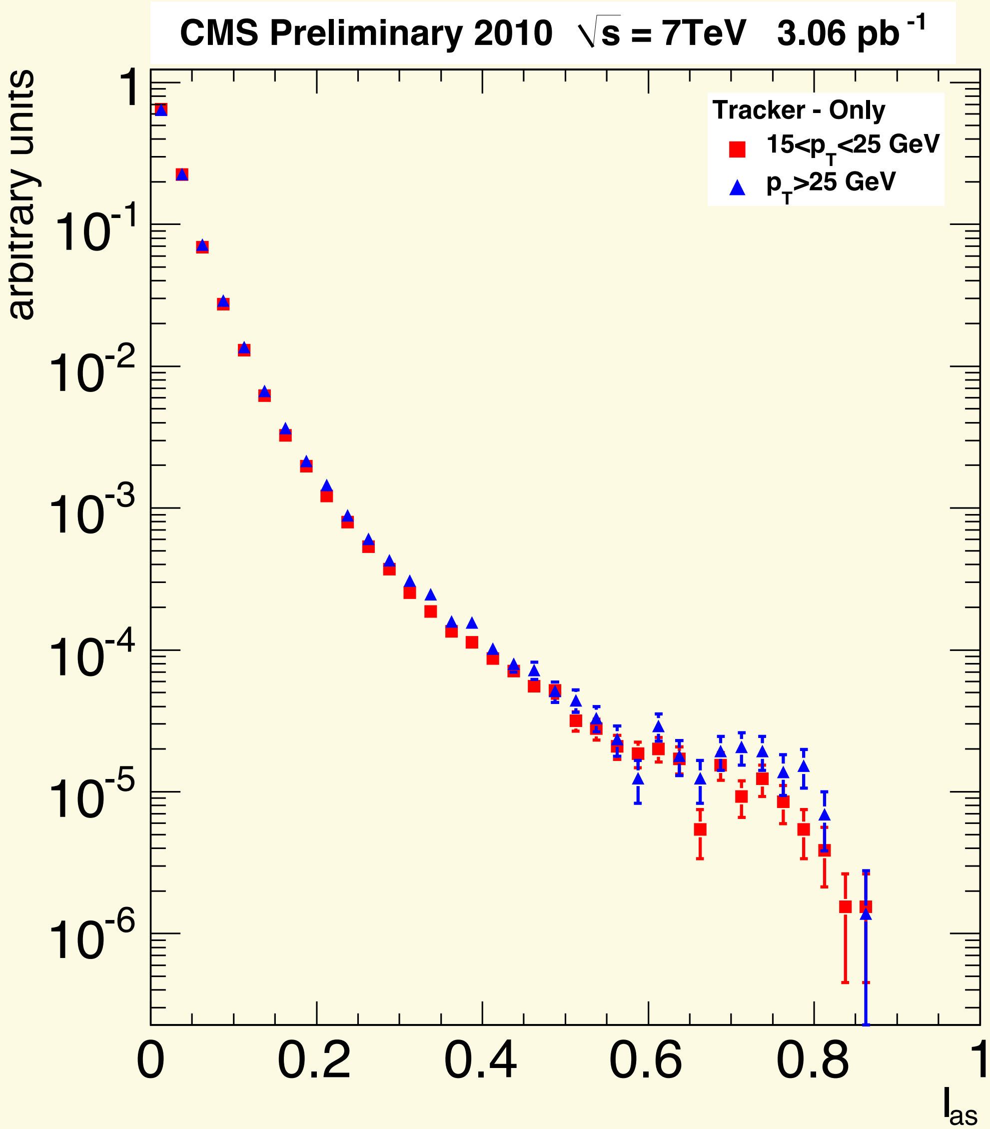
P is probability a MIP would produce a charge equal to or smaller than this.





Cut values depends on number of hits

I_{as}/I_h are uncorrelated with p_T



Allows use of an "ABCD" method to get background at high I_{as}

$$N_D = N_C \frac{N_B}{N_A}$$

B: Low P_T, high dE/dx	**D: high P_T, high dE/dx**
A: Low P_T, low dE/dx	C: high P_T, low dE/dx

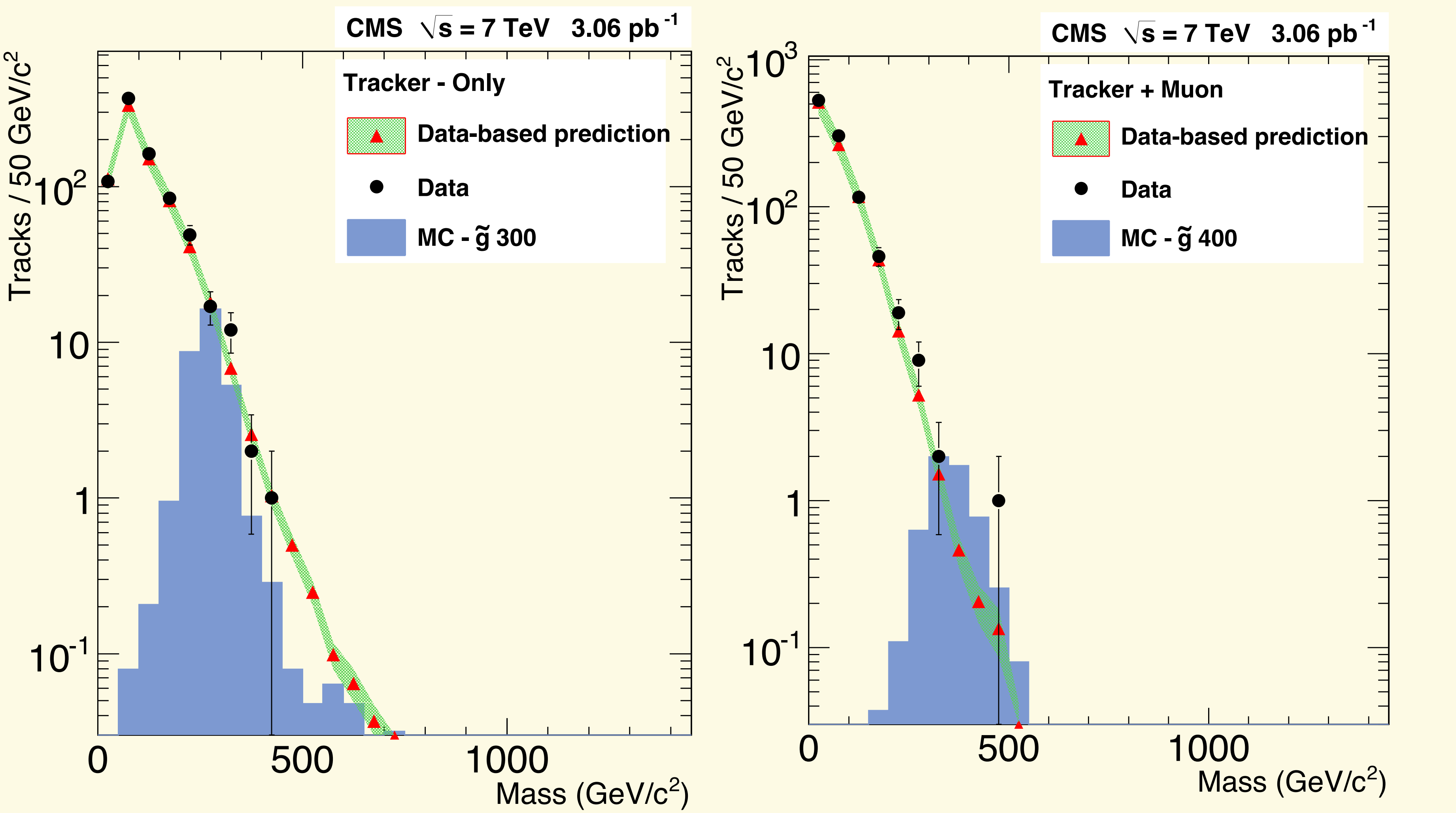
Data

$3.06 \pm 0.34\ \text{pb}^{-1}$

LOOSE	**Mu**	**Tk**
ϵ_I	3.2×10^{-2}	1.0×10^{-2}
I_{as}^{min}	0.049 - 0.162	0.007 - 0.278
ϵ_{p_T}	1.0×10^{-1}	3.2×10^{-2}
p_T^{min} (GeV/c)	34 - 36	59 - 62
Expected	$281 \pm 2(stat.) \pm 49(syst.)$	$426 \pm 1(stat.) \pm 62(syst.)$
Observed	307	452
TIGHT	**Mu**	**Tk**
ϵ_I	1.0×10^{-4}	1.0×10^{-4}
I_{as}^{min}	0.184 - 0.782	0.186 - 0.784
ϵ_{p_T}	1.0×10^{-3}	3.2×10^{-4}
p_T^{min} (GeV/c)	115 - 118	154 - 210
Expected	$0.025 \pm 0.002(stat.) \pm 0.004(syst.)$	$0.074 \pm 0.002(stat.) \pm 0.011(syst.)$
Observed	0	0

Observed Mass Spectrum

Loose Selection



Colored HSCP

$$\tilde{g}g, \tilde{g}q\bar{q}, \tilde{g}qqq$$

Long-lived gluinos and stops hadronize to metastable particle by combining with light quarks and gluons (R-hadron). Complication with r-hadrons: they can flip charge while passing through matter. Recent studies project large probability of particle being neutral after passing through a typical detector [14]. Uncertainties on energy loss in matter due to uncertainties on nuclear interactions. Uncertainties on the initial fraction of R-gluonballs (typically assumed to be 10%). We use pythia to do to the hadronization and [23] and [24] to model hadronic interactions, which are by the same authors as [14], and has a somewhat different scenario than their original work.

[14] R. Mackeprang and D. Milstead, "An Updated Description of Heavy-Hadron Interactions", *Eur. Phys. J.* **C66** (2010) 493–501, arXiv:0908.1868. doi:10.1140/epjc/s10052-010-1262-1.

[23] A. C. Kraan, "Interactions of heavy stable hadronizing particles", *Eur. Phys. J.* **C37** (2004) 91–104, arXiv:hep-ex/0404001. doi:10.1140/epjc/s2004-01997-7.

[24] R. Mackeprang and A. Rizzi, "Interactions of coloured heavy stable particles in matter", *Eur. Phys. J.* **C50** (2007) 353–362, arXiv:hep-ph/0612161. doi:10.1140/epjc/s10052-007-0252-4.

Sensitivity to different models

gluino mass (GeV/c^2)	200	300	400	500	600	900
Theoretical cross section (pb)	606	57.2	8.98	1.87	0.470	0.0130
Mu; f=0.1						
Total acceptance (%)	7.17	10.4	13.1	15.1	14.5	9.18
Expected 95% C.L. limit (pb)	15.1	10.4	8.25	7.16	7.47	11.8
Observed 95% C.L. limit (pb)	14.5	9.98	7.92	6.88	7.17	11.3
Mu; f=0.5;						
Total acceptance (%)	3.84	5.46	7.03	8.23	8.10	4.98
Expected 95% C.L. limit (pb)	28.2	19.8	15.4	13.1	13.3	21.7
Observed 95% C.L. limit (pb)	27.1	19.0	14.8	12.6	12.8	20.9
Tk; f=0.1; ch. suppr.						
Total acceptance (%)	0.59	2.44	4.16	6.39	8.60	7.66
Expected 95% C.L. limit (pb)	188	45.5	26.7	17.4	12.9	14.5
Observed 95% C.L. limit (pb)	176	42.6	25.0	16.2	12.1	13.6

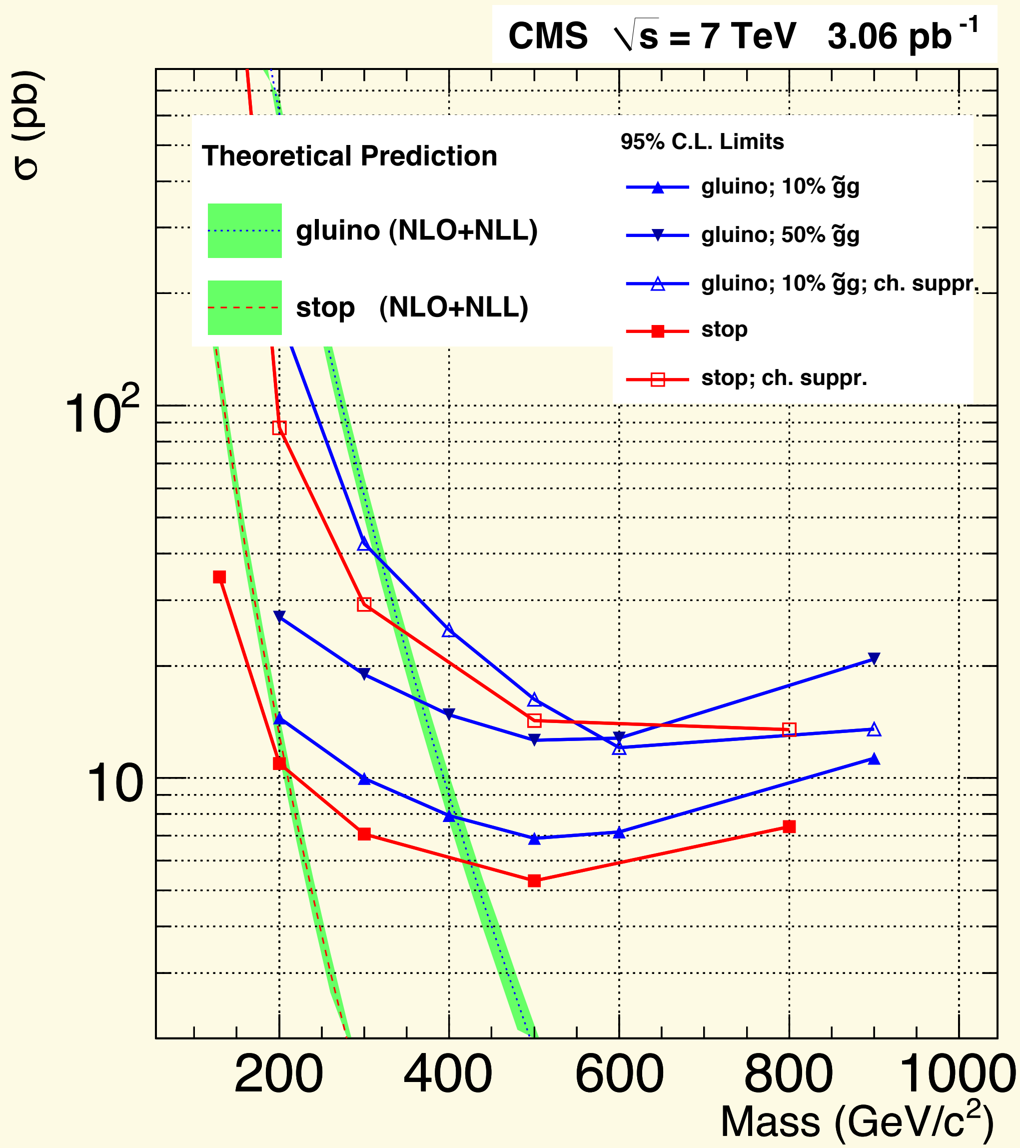
stop mass (GeV/c^2)	130	200	300	500	800
Theoretical cross section (pb)	120	13.0	1.31	0.0480	0.00110
Mu;					
Total acceptance (%)	2.99	9.50	14.7	19.6	14.0
Expected 95% C.L. limit (pb)	36.1	11.4	7.35	5.52	7.71
Observed 95% C.L. limit (pb)	34.7	10.9	7.06	5.30	7.39
Tk; ch. suppr.					
Total acceptance (%)	0.02	1.19	3.55	7.27	7.68
Expected 95% C.L. limit (pb)	5540	93.2	31.3	15.3	14.5
Observed 95% C.L. limit (pb)	5180	87.2	29.2	14.3	13.5

Acceptances under different assumptions.

Ch. Suppr. means any interactions makes particle neutral.

f is the fraction that hadronize into (neutral) gluballs at production

Limits



CMS limit: gluino 398 (357) (311) for degnerate gluino/ sqark and f of 0.1 (0.5) (ch. supressed uses f=0.1). Stop is 202.

From CDF:
Stop: 249
Gluino: 322 (squark gluino degenerate) - 397 (heavy quark), with f=0.1

Cross sections NLO+NLL by prospino2

Stopped r-hadrons

Stopped muons from the ICARUS T600

Muon ranges out in calorimeter, then decays to an electron (plus neutrinos)

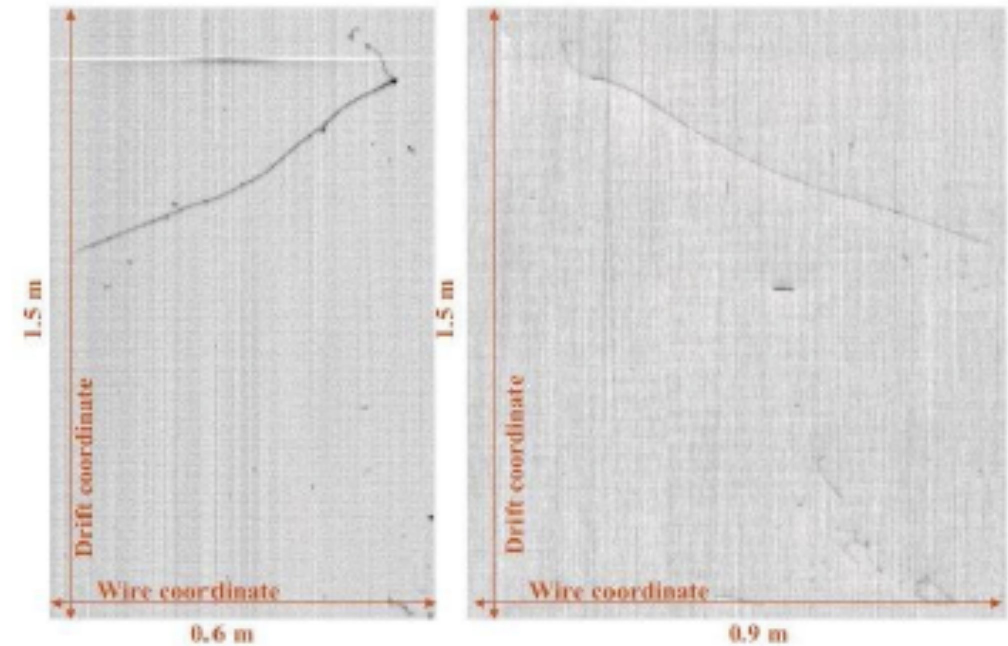
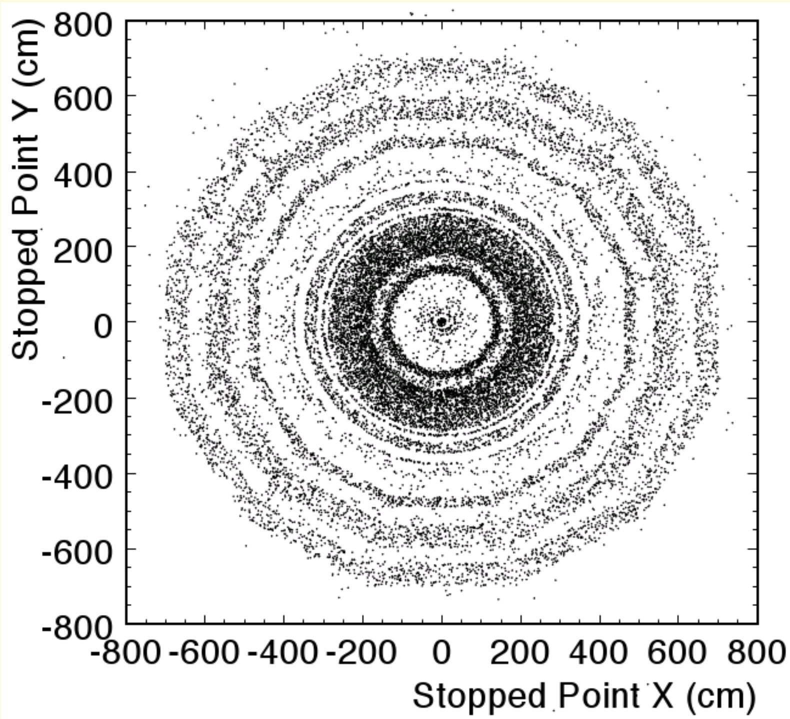


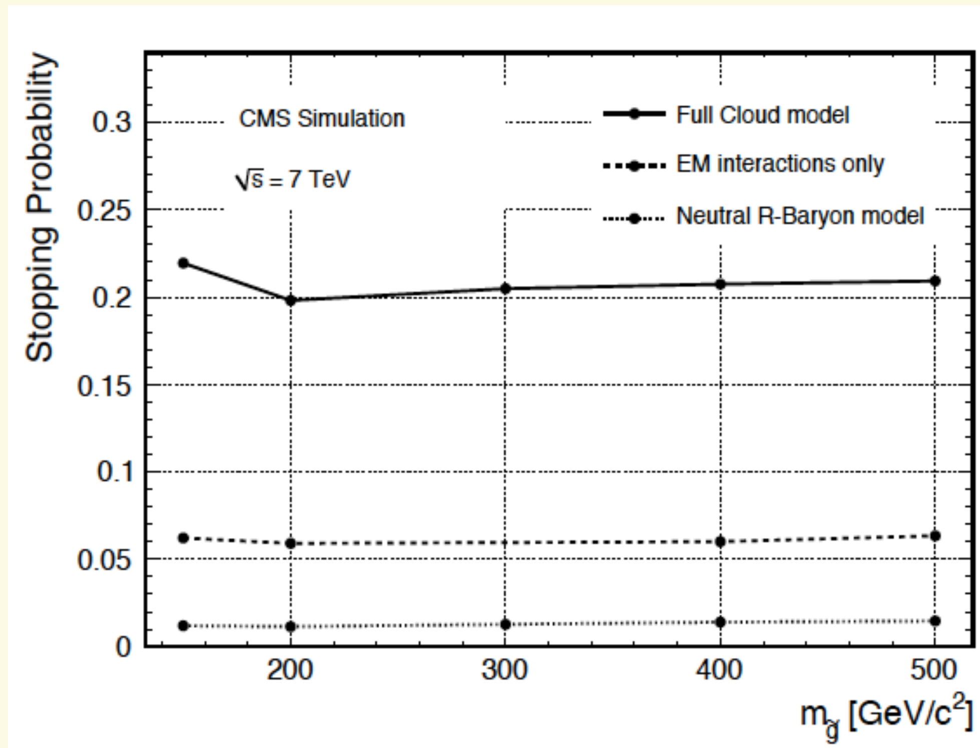
Fig. 1. Run 966 Event 8 Right chamber: muon decay event views corresponding to the Collection (left) and second Induction (right) wire planes.

This search: hadronized gluino ranged out and then decays to Jet(s) (+MET). Sensitive to $\beta<0.4$

Production and stopping



50% of these stop in HCAL. We require η<1.3 and only use HCAL energies.



When stop

$\Delta^{++}_{\tilde{g}}$ 49%

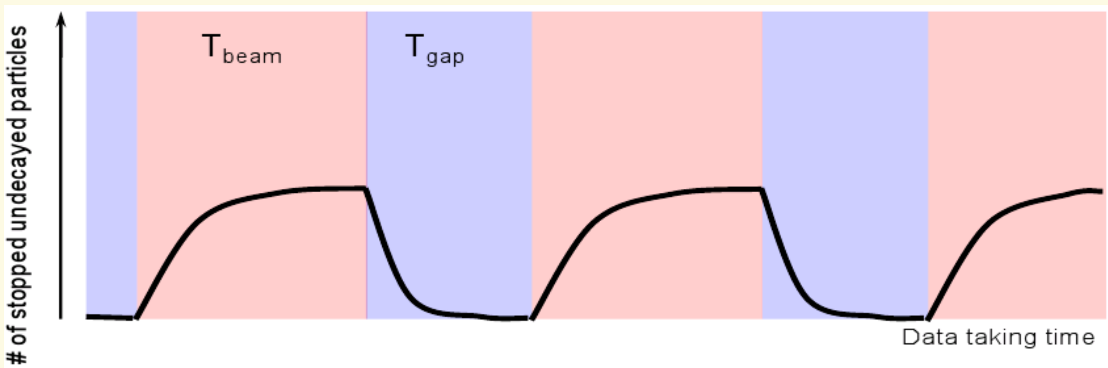
$\Delta^{+}_{\tilde{g}}$ 20%

$\Delta^{-}_{\tilde{g}}$ 25%

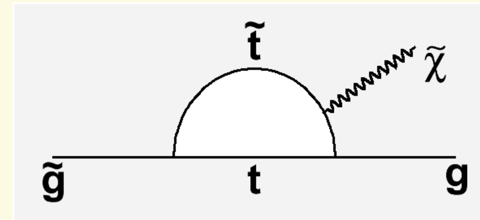
R-meson 6%

Decays

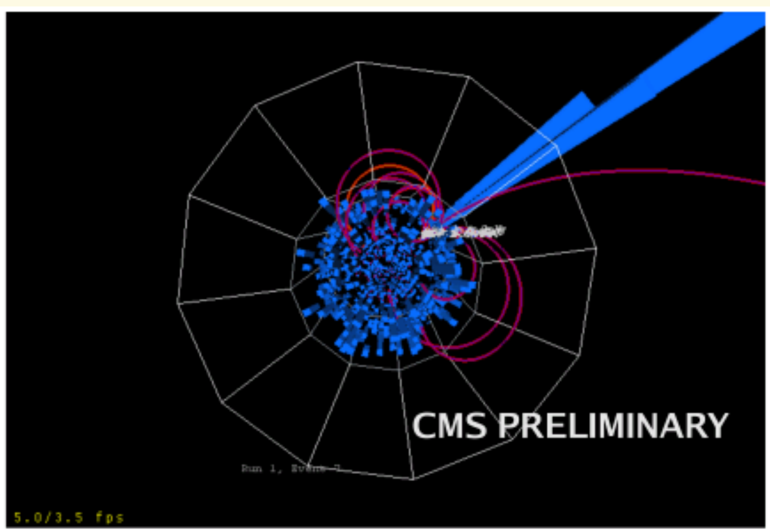
$$\Delta_{\tilde{g}}^{++} \rightarrow \tilde{g}u(uu) \rightarrow g\tilde{\chi}_1^0 u(uu)$$

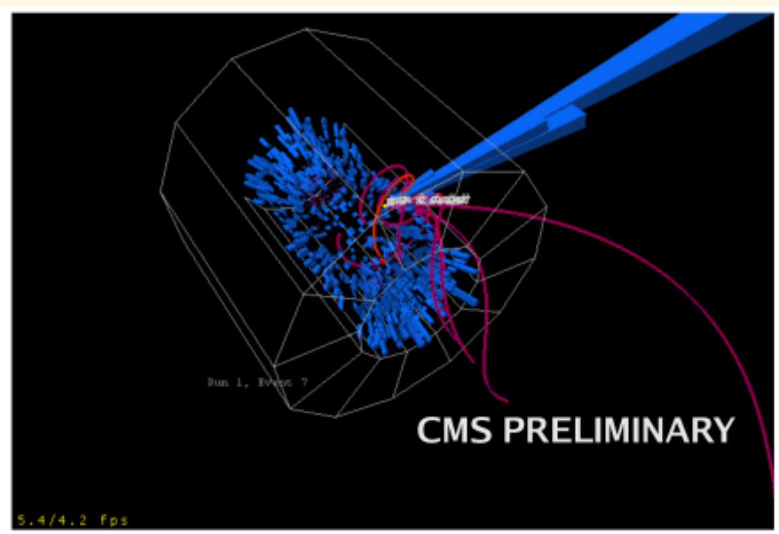


Sensitive to wide range of lifetimes by looking when beam is off



Trigger: jet trigger requiring E>20 GeV in coincidence with no signal on the beam pickup monitors.

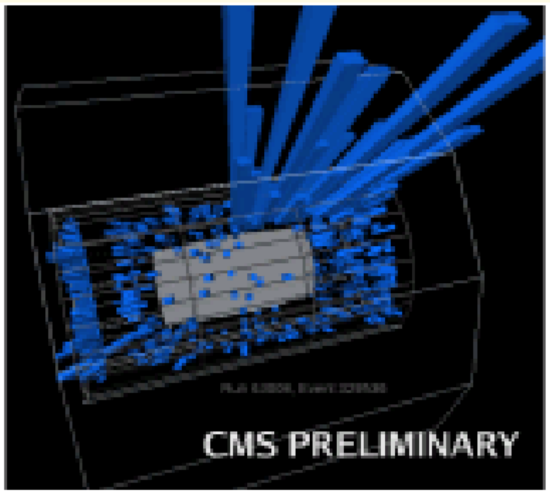


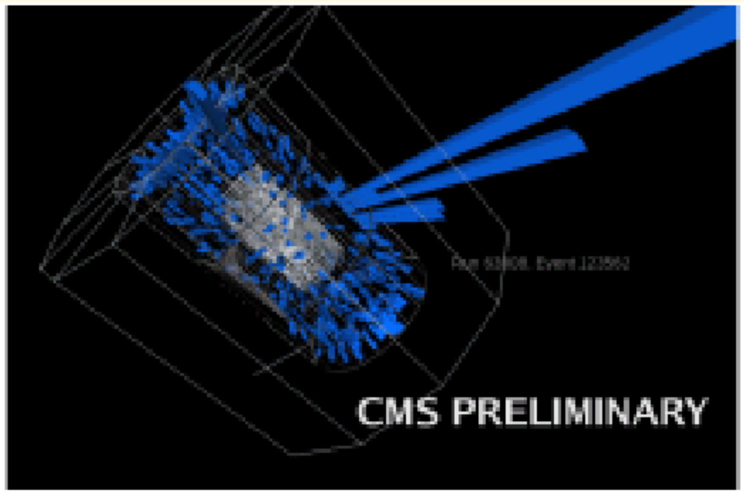


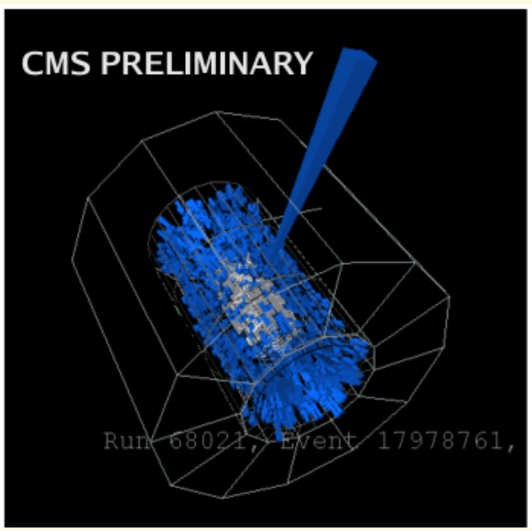
Background Rejection

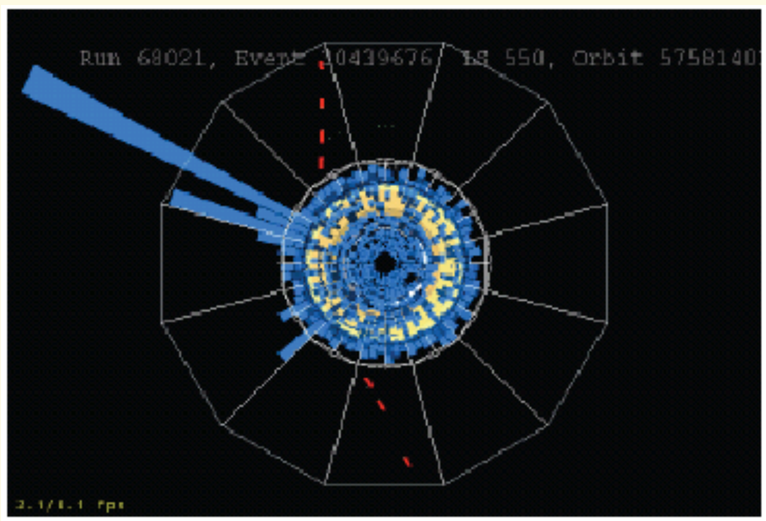
- Reject real collisions
  - reject if either beam monitor fired
  - reject if in beam crossing within -2 to 1 of collision BX
  - reject if has reconstructed vertex
- Reject non-beam sources of particles
  - reject if fails beam halo filter
  - reject if reconstructed muon in muon system (cosmic filter)

Background





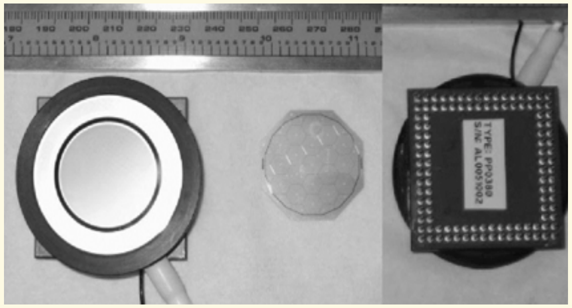


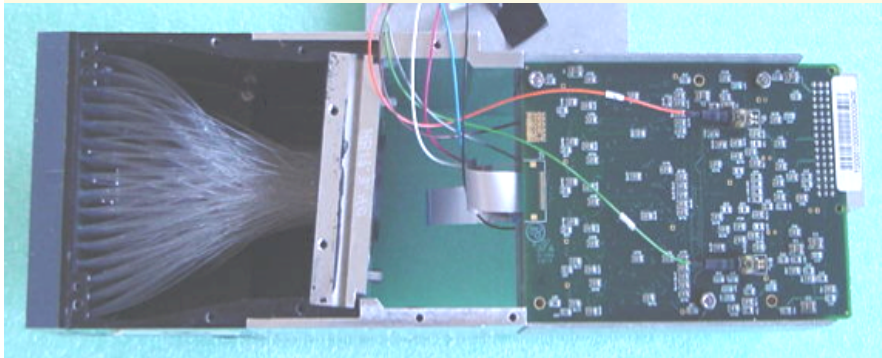


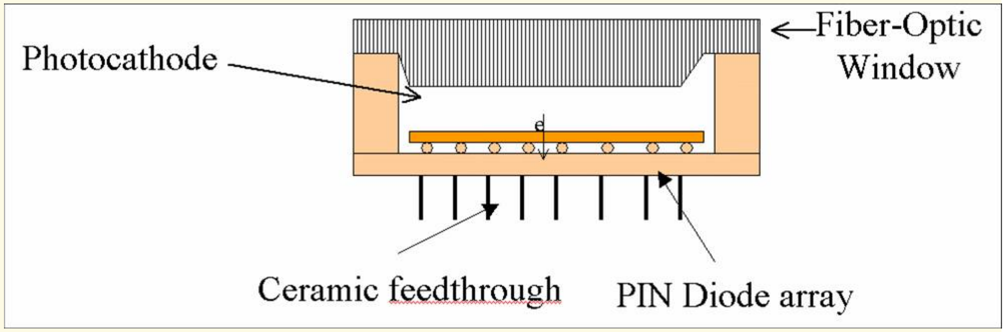
Data taken during cosmic ray data taking shows cosmics and HPD discharge

Hybrid Photo-diode (HPD)

- QE ~ 15%
- Gain 1500 ~ 2000 depending on voltage
  - Running at high voltage, 7~8kV
- Has typical features of vacuum tubes:
  - Discharges (HV + dielectric!) but at a low rate
  - Some ion feedback
- Very complex optical-to-HPD (ODU)





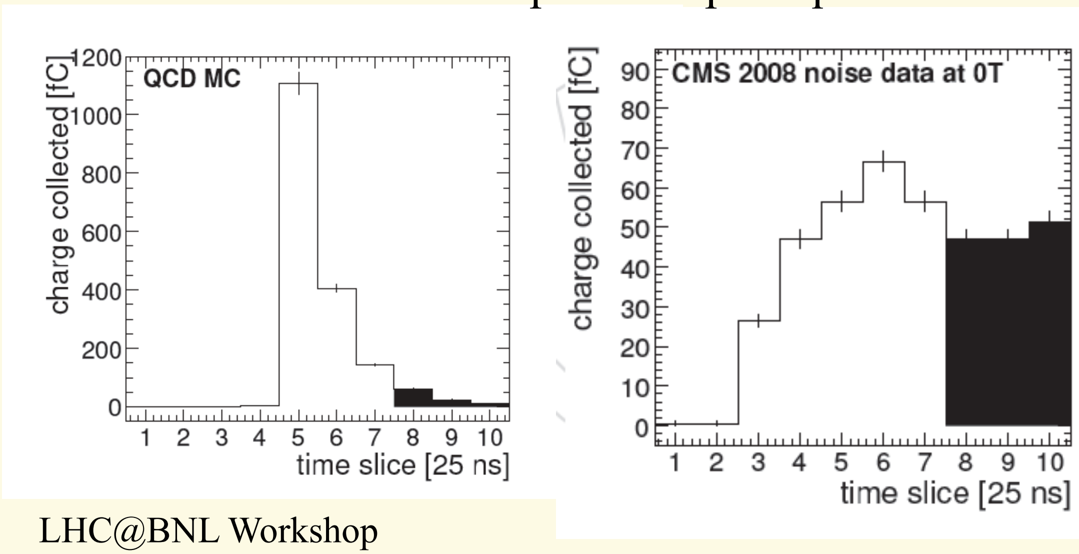


Additional noise reduction

Reject if looks like HPD noise

- E> 50 GeV
- reject if 90% of energy is in ≤3 towers
- require leading jet have 60% of its energy in <6 towers
- reject if 5 or more leading towers have same φ
- reject if 95% of the jet energy is at same φ
- pulse shape requirements

Illustration of pulse shape requirement



Data Observations

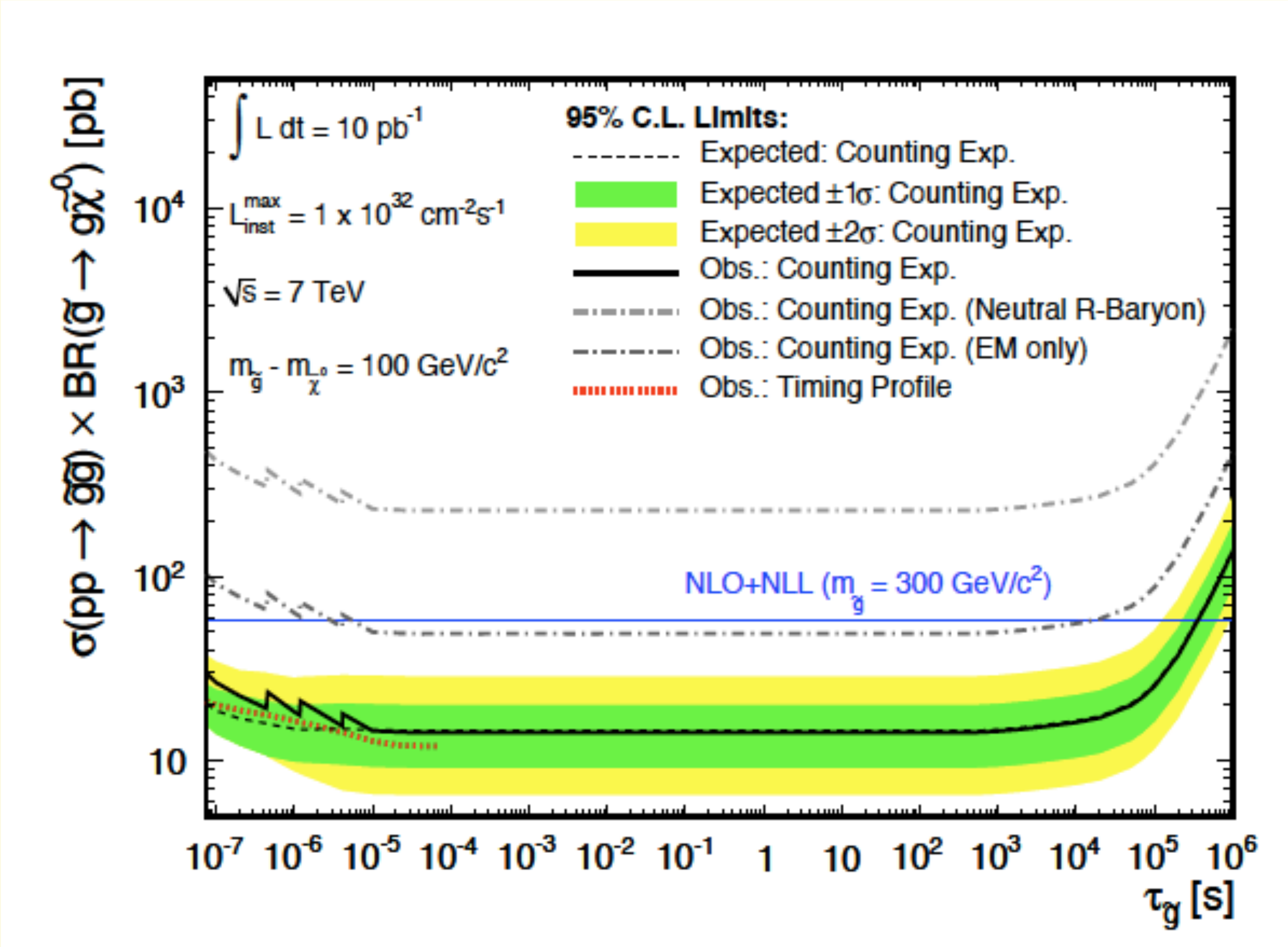
Noise rate is calculated using 95 hours taken at 2-7x10^{27} $cm^{-2}s^{-1}$. Search sample was taken with 62 hours at higher intensities with 312 proton bunches per beam.

Any small dependence of noise rate with time handled by releasing cuts in the data sample, and scaling it by the rejection of that cut as measured in the control sample. Average over different reference cuts used as final rate. 23% uncertainty on rate.

Table 1: Results of counting experiments for selected values of $\tau_{\tilde{g}}$. Entries between 1×10^{-5} and 1×10^{6} s are identical and are suppressed from the table.

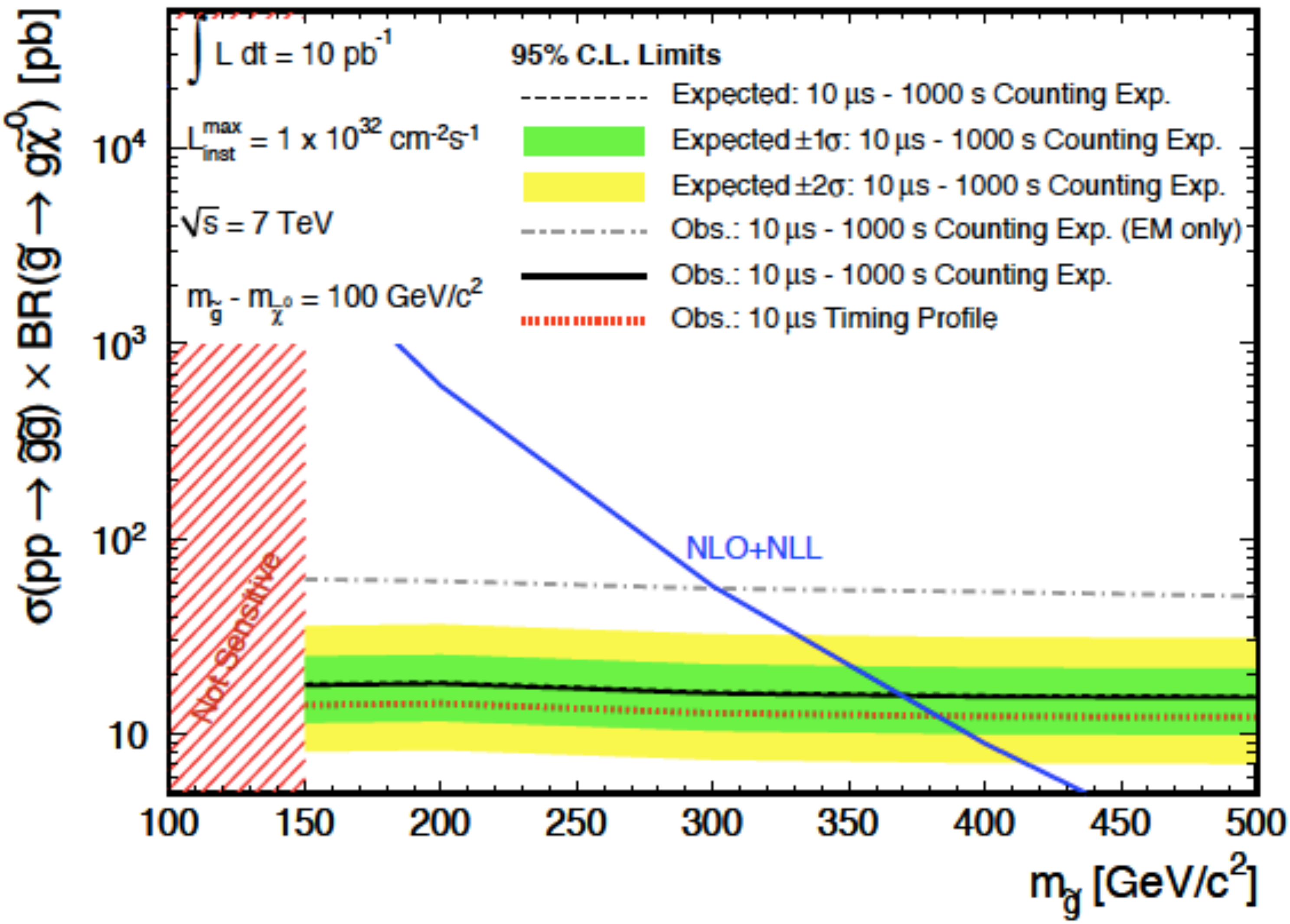
Lifetime [s]	Expected Background ($\pm$ stat. $\pm$ syst.)	Observed
1×10^{-7}	$0.8 \pm 0.2 \pm 0.2$	2
1×10^{-6}	$1.9 \pm 0.4 \pm 0.5$	3
1×10^{-5}	$4.9 \pm 1.0 \pm 1.3$	5
1×10^{6}	$4.9 \pm 1.0 \pm 1.3$	5

Results: σ x BR



Limit from both a counting experiment and a fit to the time distribution

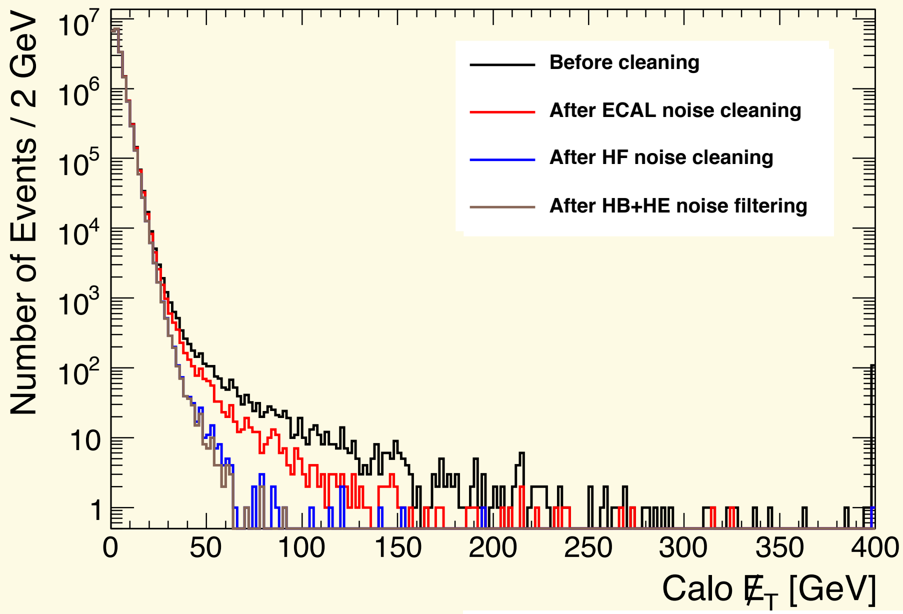
Results: Gluino Mass Limit

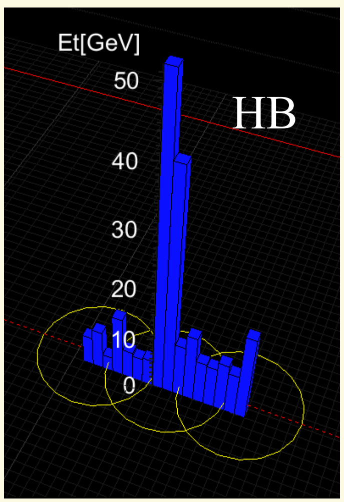


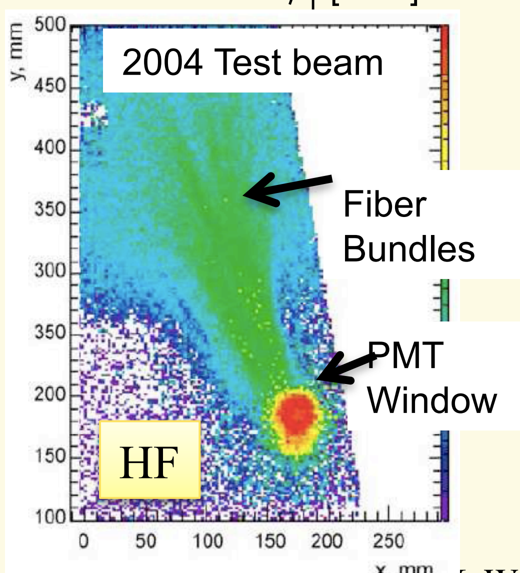
MET

Is it useable?
YES!!!

Cleanup





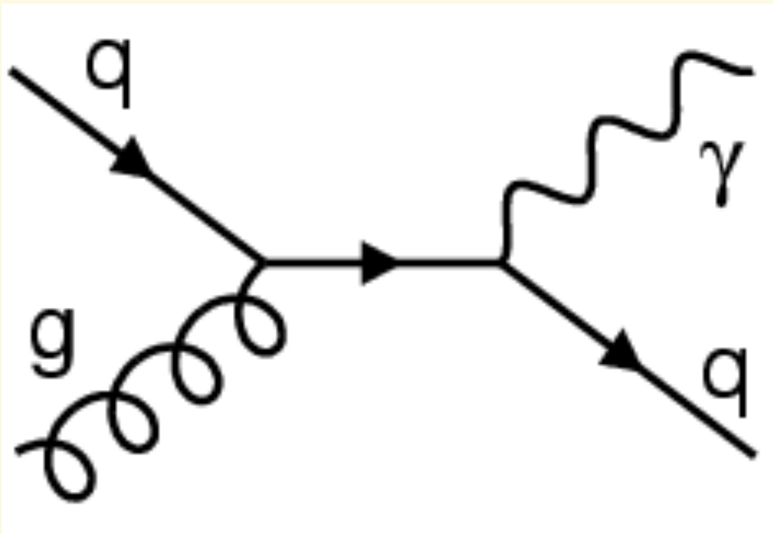


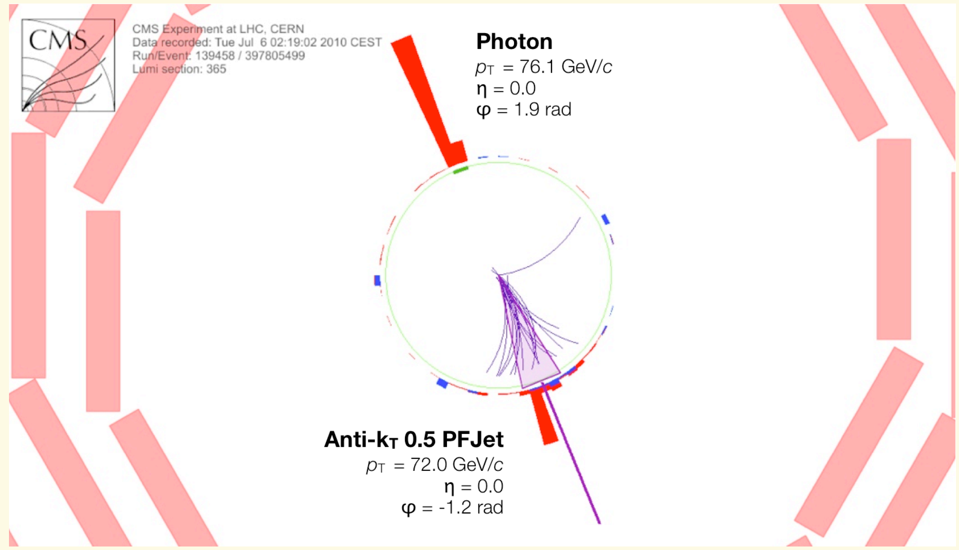
Main sources of anomalous energy are:

- EB APD's
- Cherenkov radiation in HF phototubes
- Scintillation light in HEM "3M radiant mirror film" sleeve connecting HF light pipe to phototube. Will be switched to tyvek.

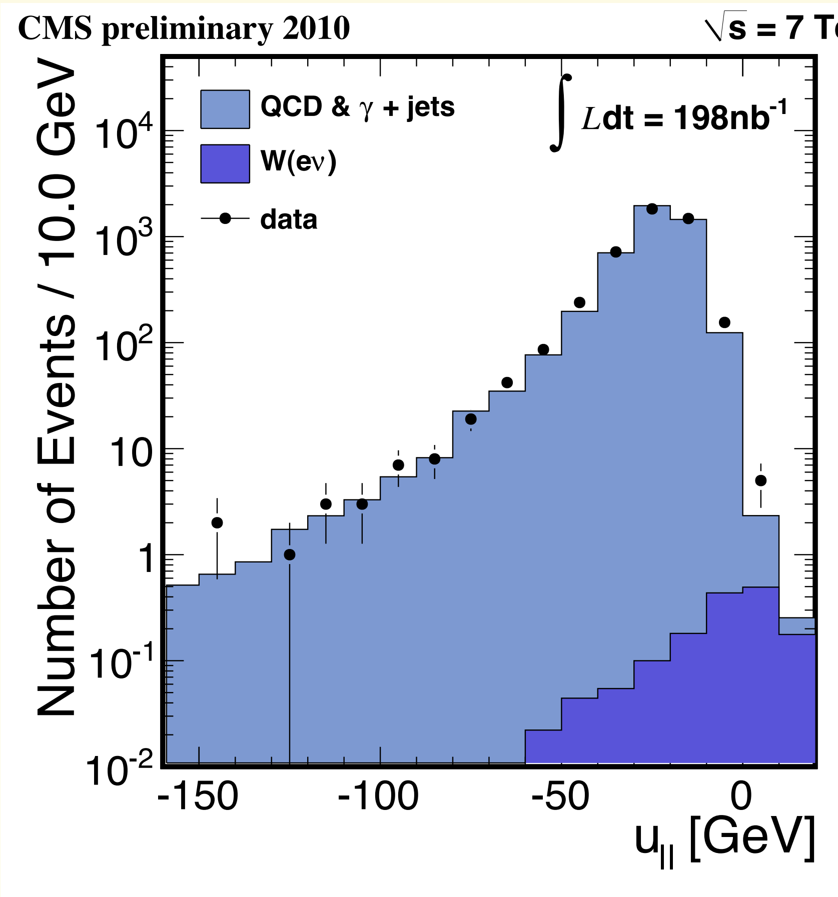
Performance

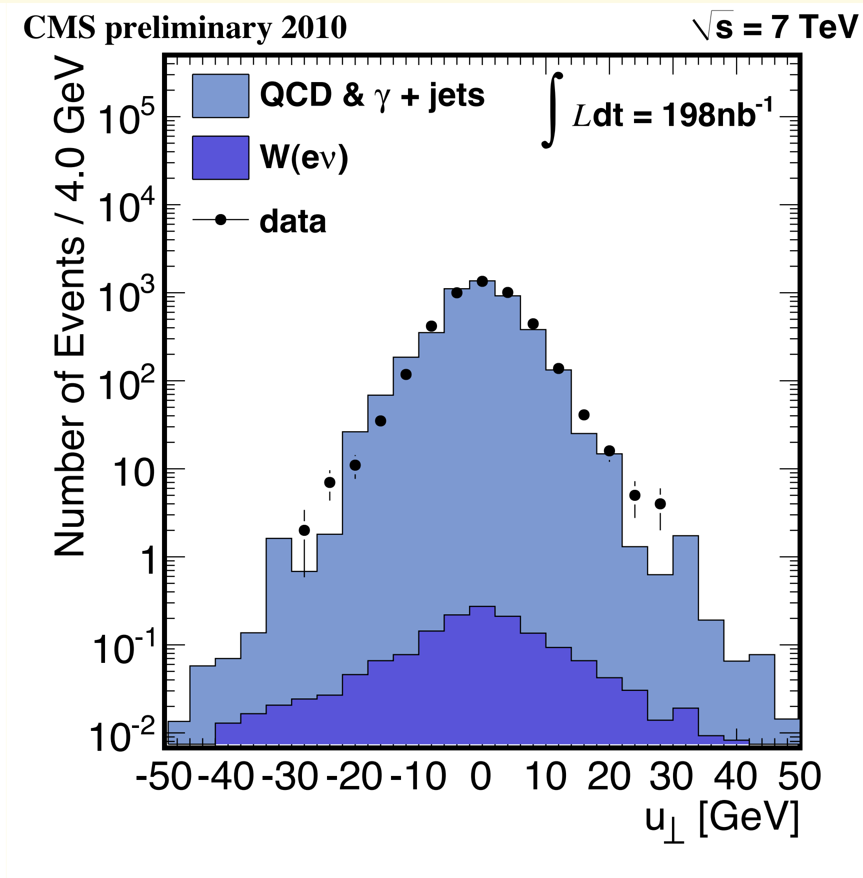
Checked in data using γ+X events

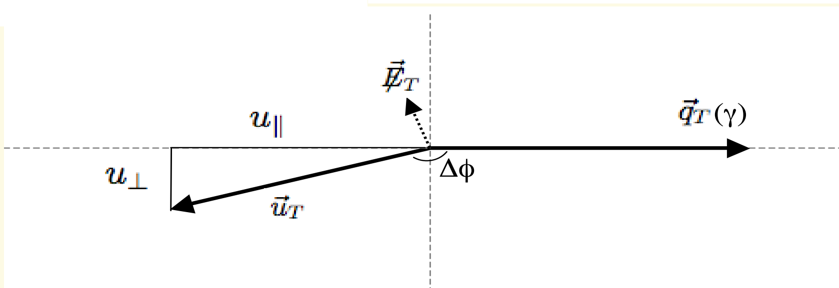




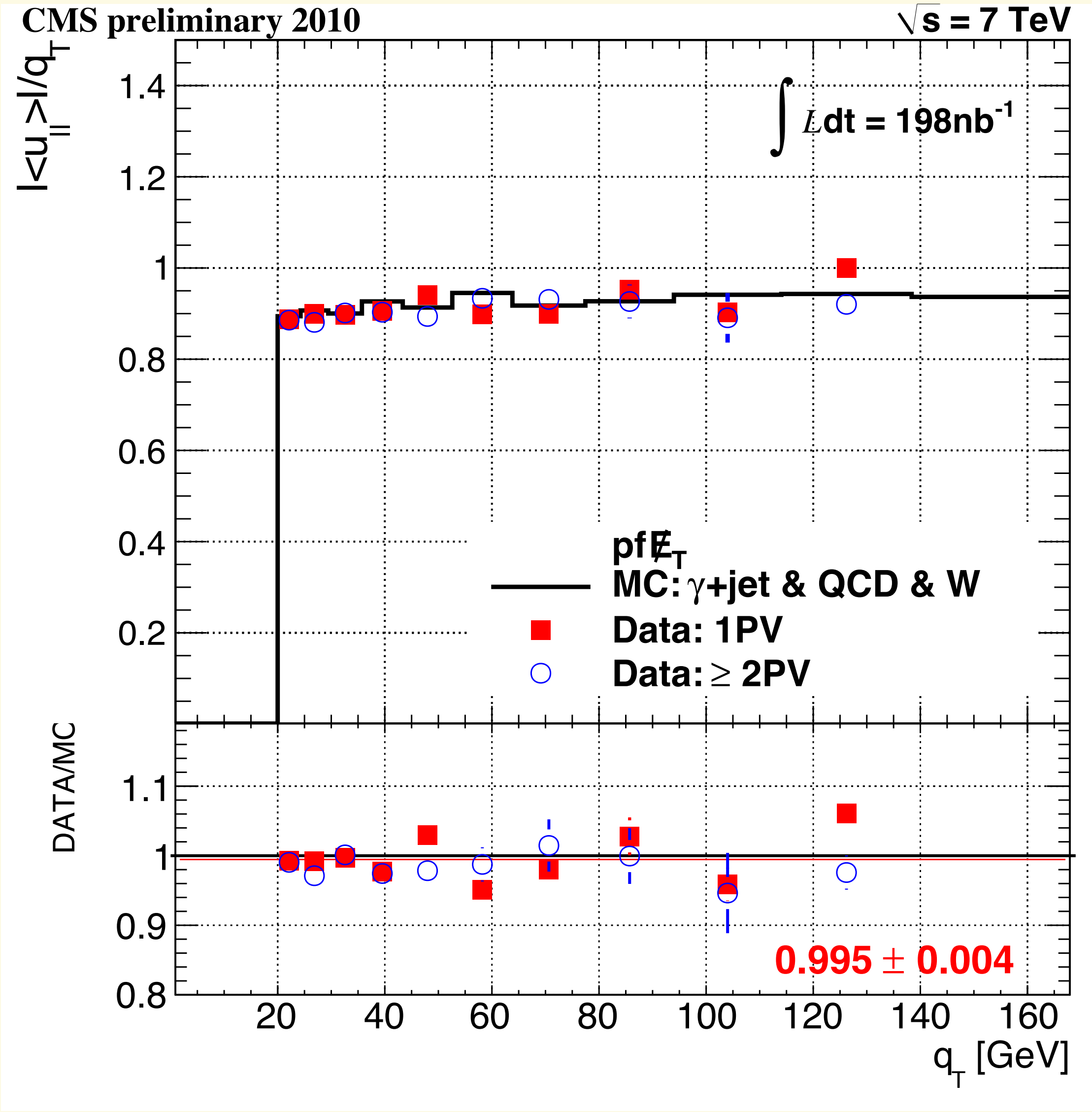
MET components







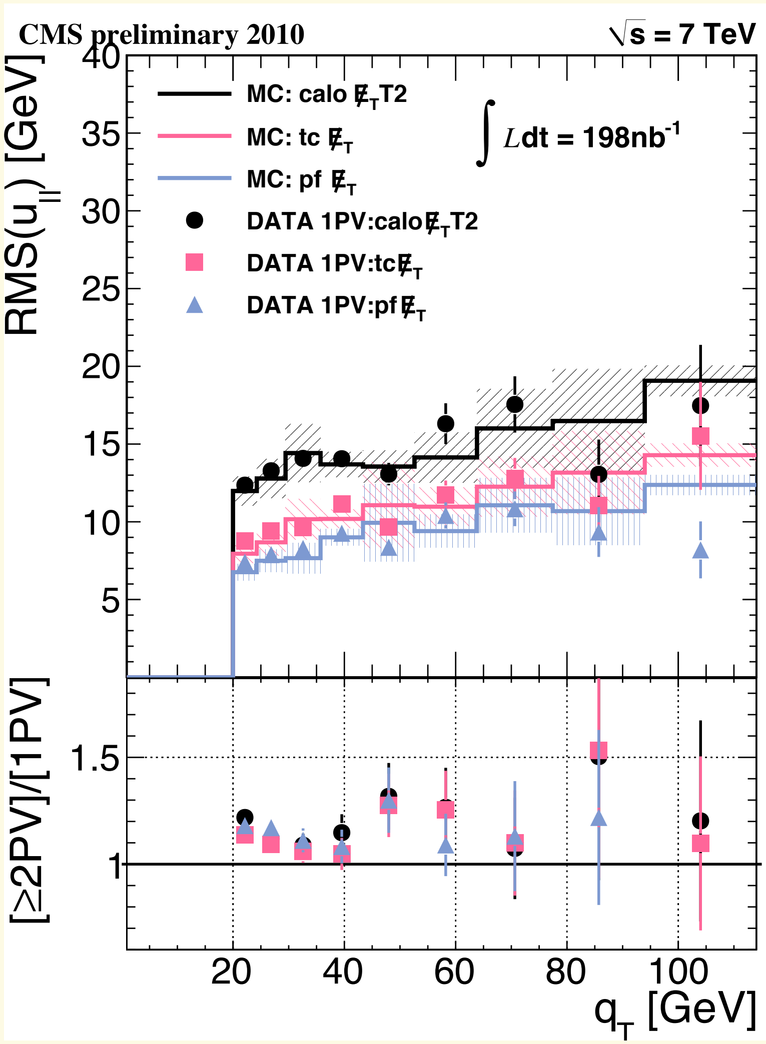
MET Scale

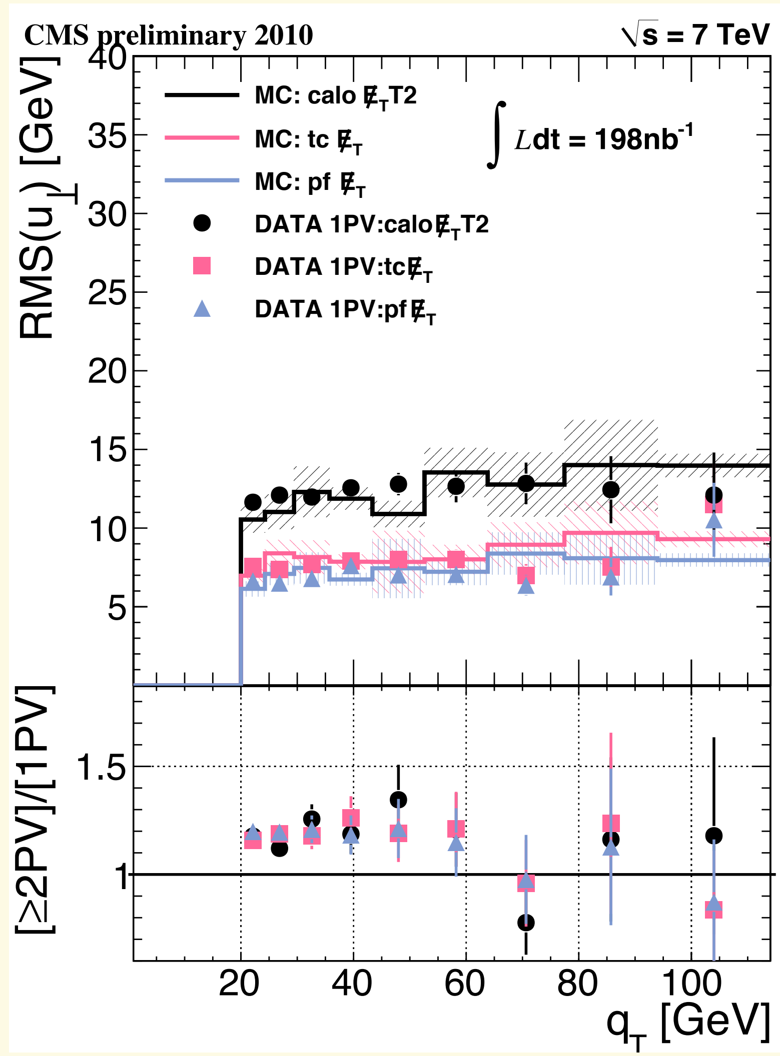


Independent of pileup
Ratio <1 since JES scale corrections were not applied for this plot.

MET Resolution

Considerable improvement of resolution by addition of tracking information





Conclusions

SUSY Search at CMS has started!

• new limits on heavy stable charged particles

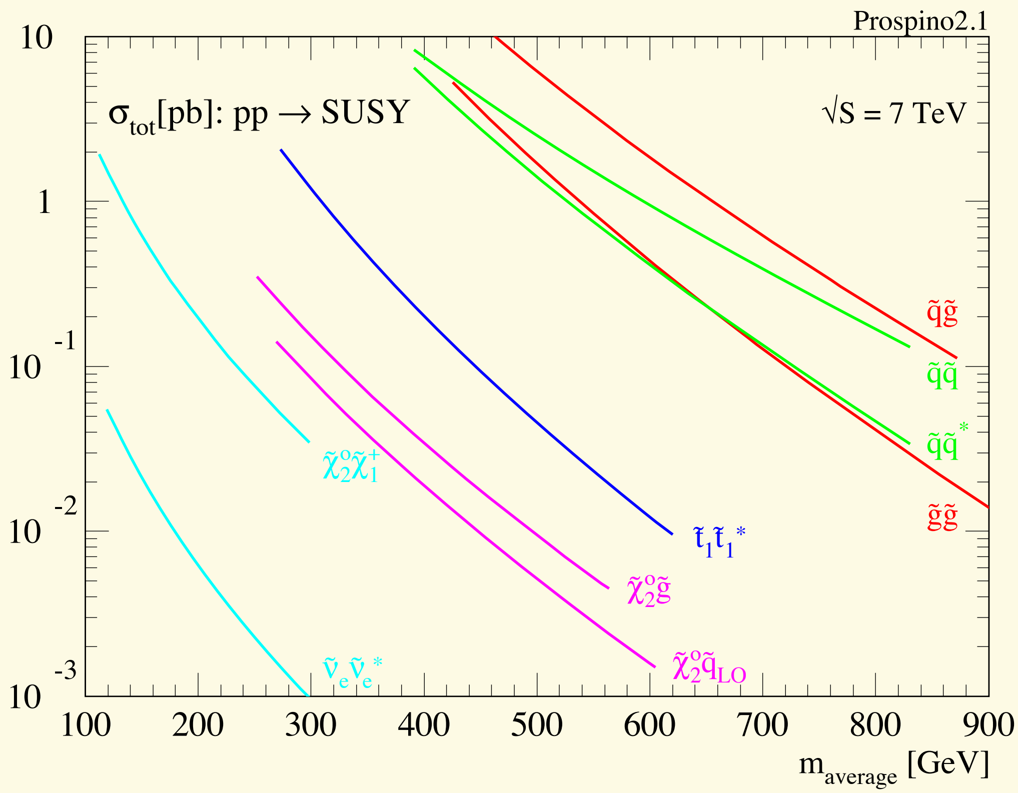
• new limits on squarks/gluinos decaying to jets and MET

• MET is commissioned and working well!

• Eager for the 8 TeV data!

Stay tuned for more results soon.

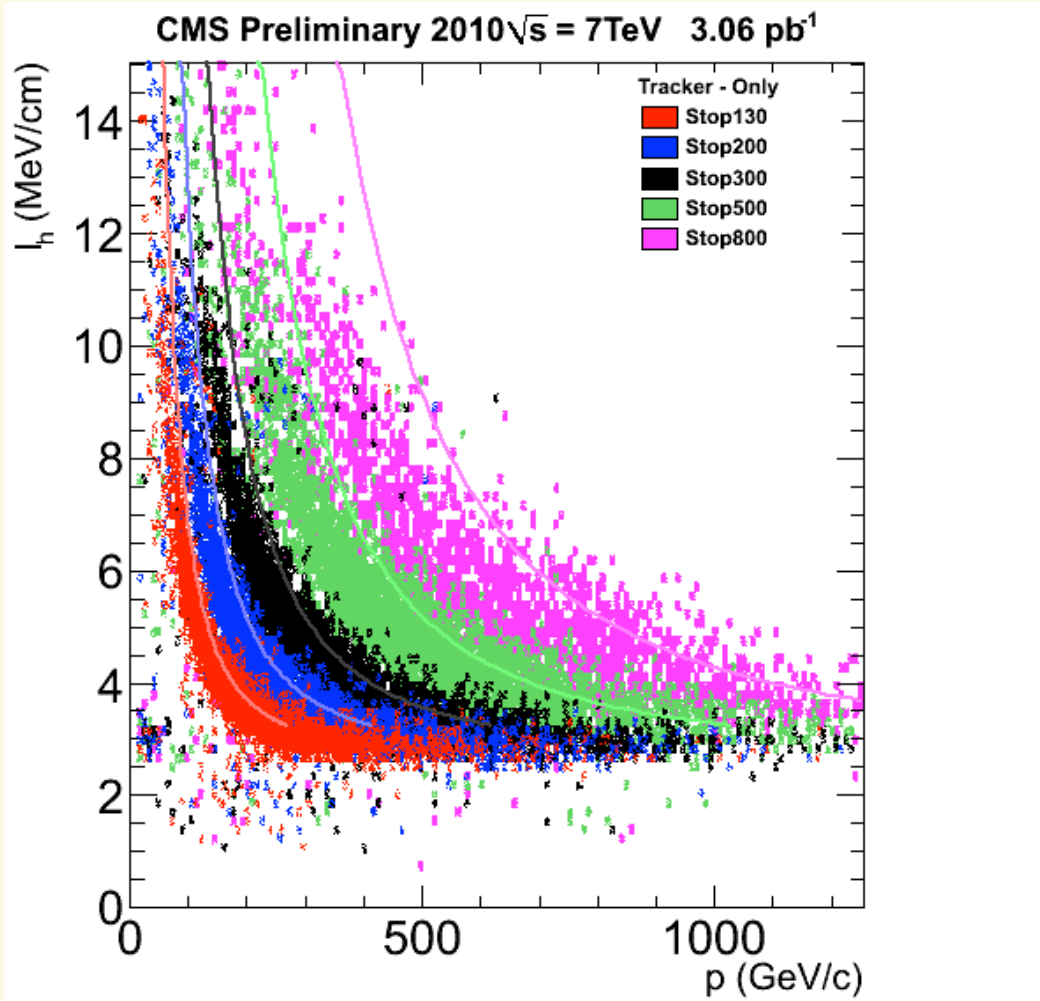
SUSY at 7 TeV



With only 36 pb^{-1}, will look for large cross sections (squark/gluino) in inclusive channels

- stable gluinos
- “classic” SUSY with squarks/gluinos decaying to jets and MET
- expect more results for “ski” conferences

Large mass



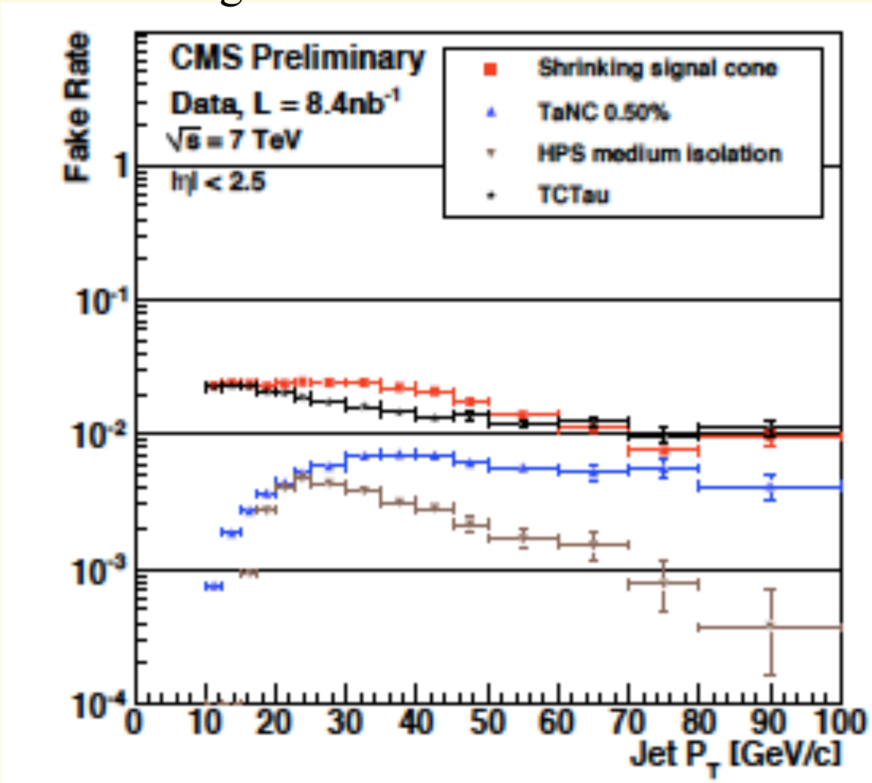
For masses > 100 GeV: Bias due to ADC truncation at high mass: ADC max is roughly 3 MIPs

Basic Object Performance

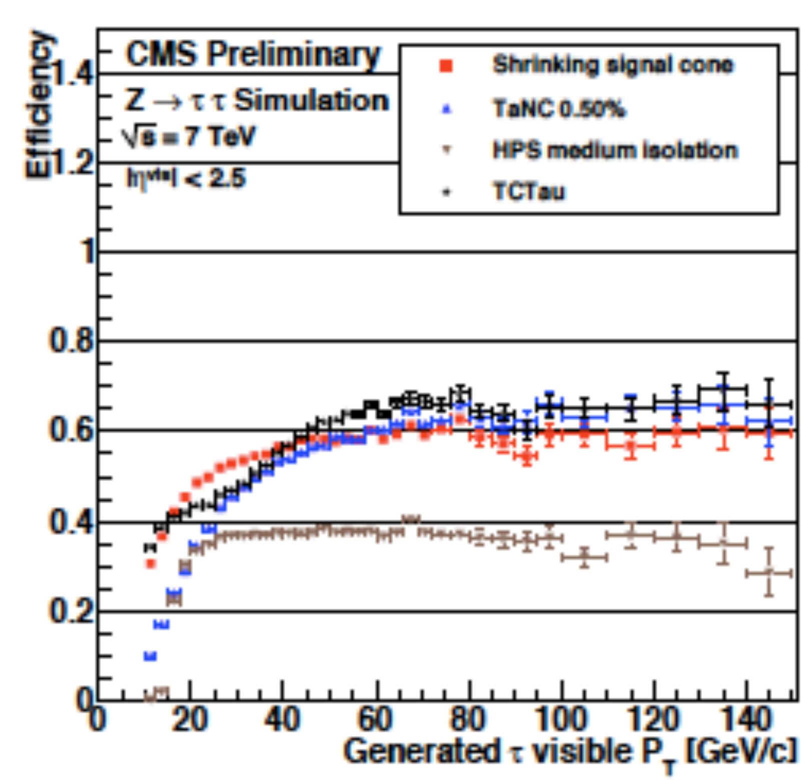
TAUS

PFT-10-004

Log scale



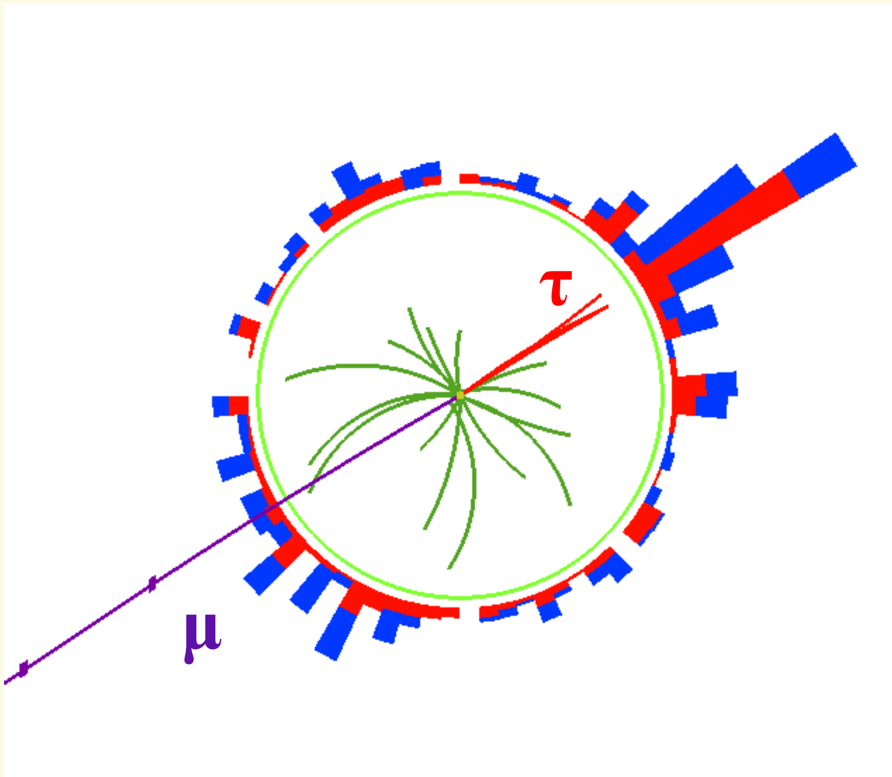
Linear scale

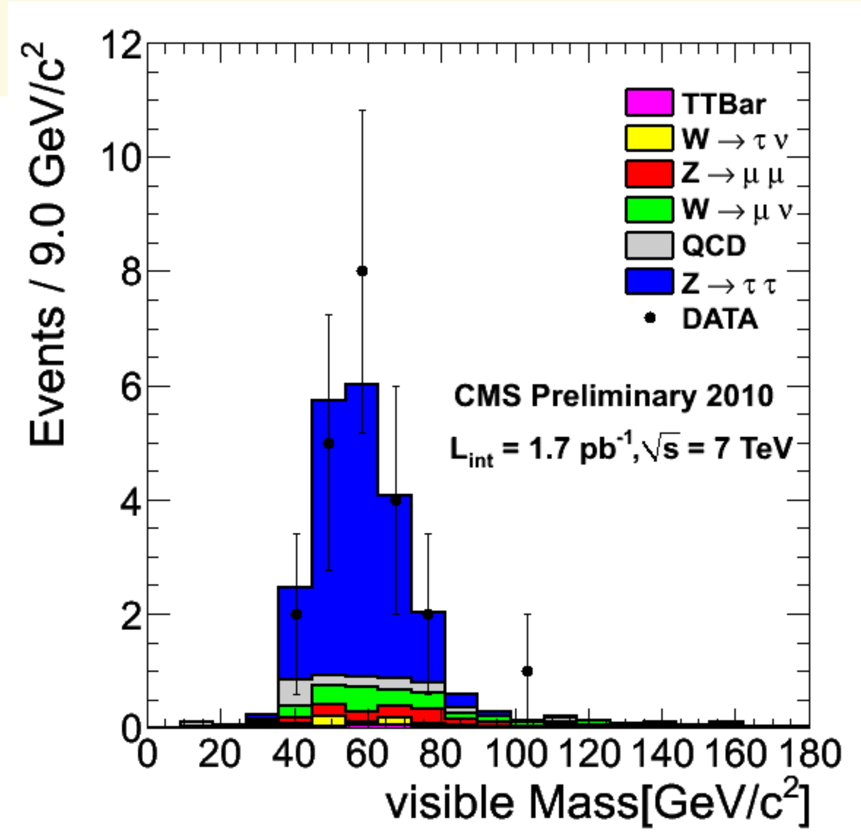


Two simple cone algorithms
HPS: PFlow-based tau ID employs cuts on multiplicity and invariant mass of charged hadrons and neutral pions in a cone DR=2.8/T, with veto on additional particles above a PT cut in the cone
TaNC: pFlow+neutral net

At 60 GeV, reduction in efficiecy by 0.7 gives reduction in fake rate of 3.5 for HPS compared to next best (pflow neutral net based)

Taus

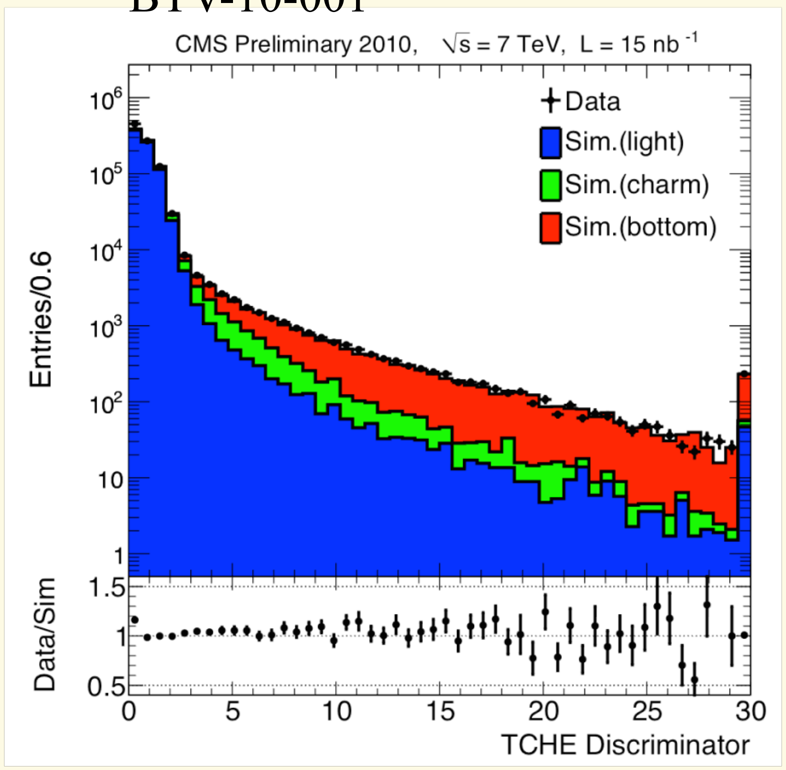


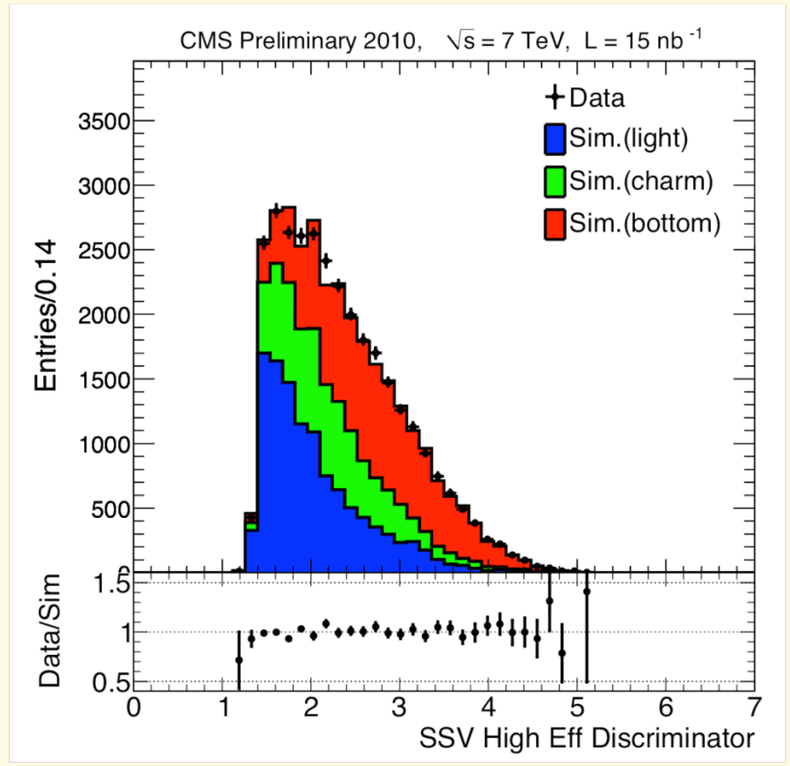


- Isolated Mu Pt > 15 GeV/c
- Isolated HPS Tau Pt > 20 GeV with loosened isolation compared to previous slide

B's

5 different types of taggers. Two in common use in physics analysis.
Data/mc agreement in 8-15 nb-1 of min bias data
BTV-10-001

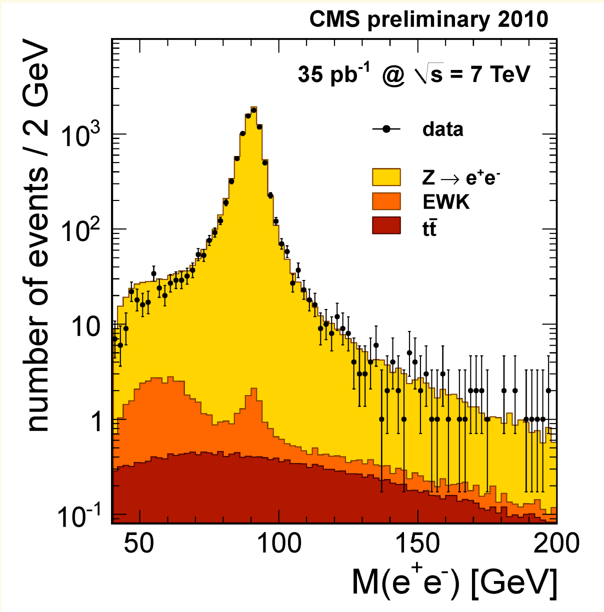


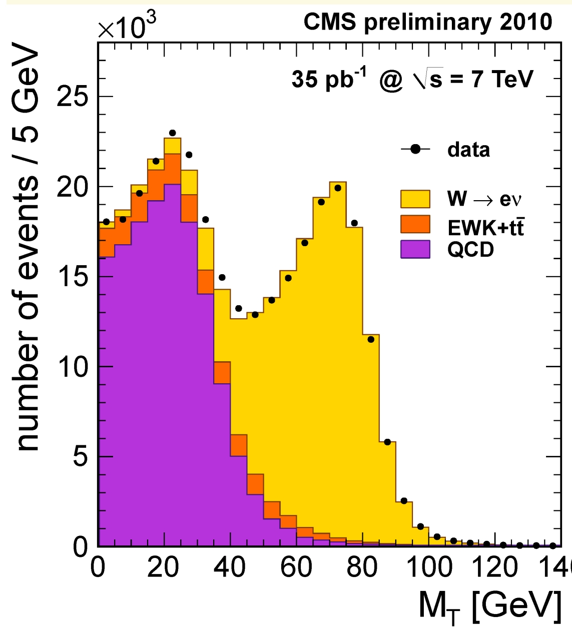


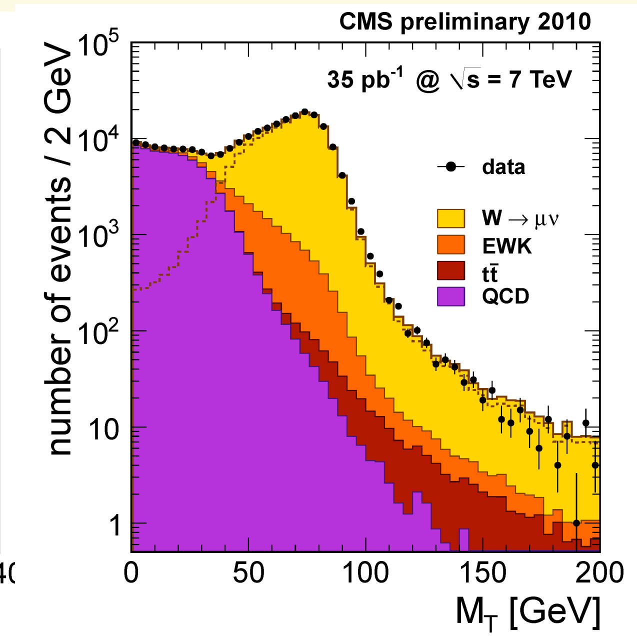
Track Counting High Efficiency.
X axis is impact parameter significance of 2nd track.
Used in top cross section paper

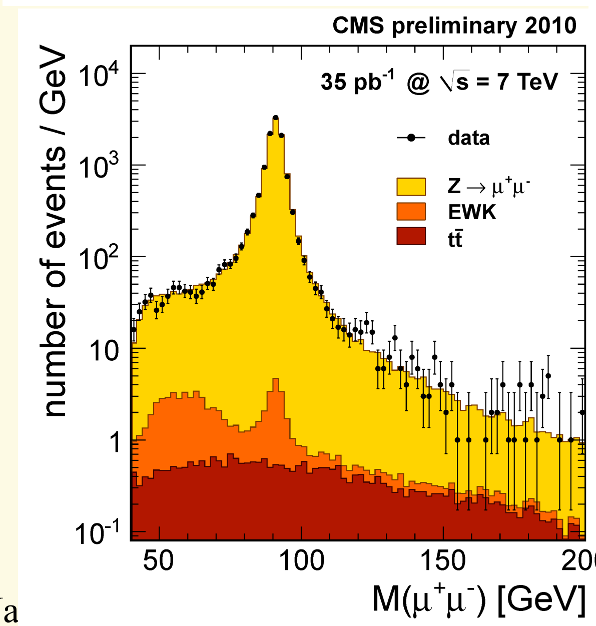
Secondary vertex explicitly reconstructed. Output is significance of 3D flight distance.
Used in b cross section pas

Electrons and Muons









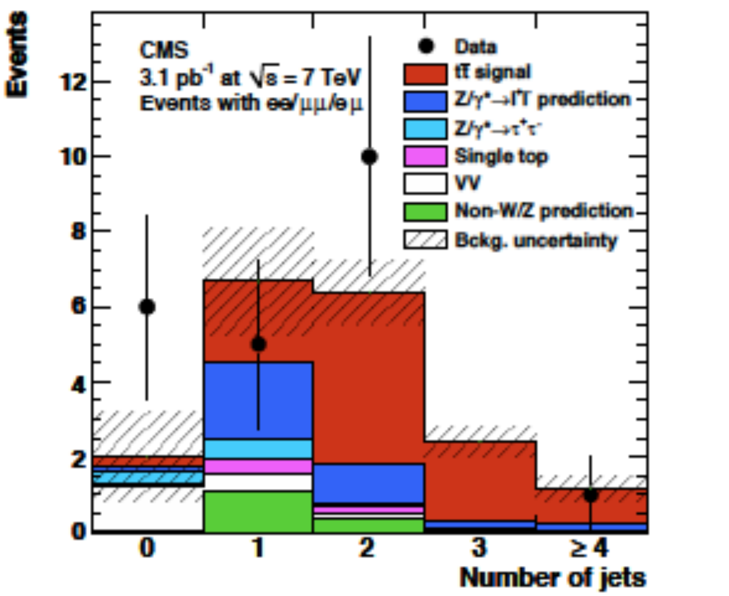
Scale, resolution, efficiency. All understood quite well enough for susy. Tails on muon PT spectrum are understood.
Fake rates in various environments can be more challenging, especially for electrons.

Backgrounds to Classic SUSY

$t\bar{t}$ to dileptons

hep-ex 1010.5994v1, published Physics Letters B (2010, doi:10.1016/j.physletb.2010.11.058)

$3.1\ \mathrm{pb}^{-1}$



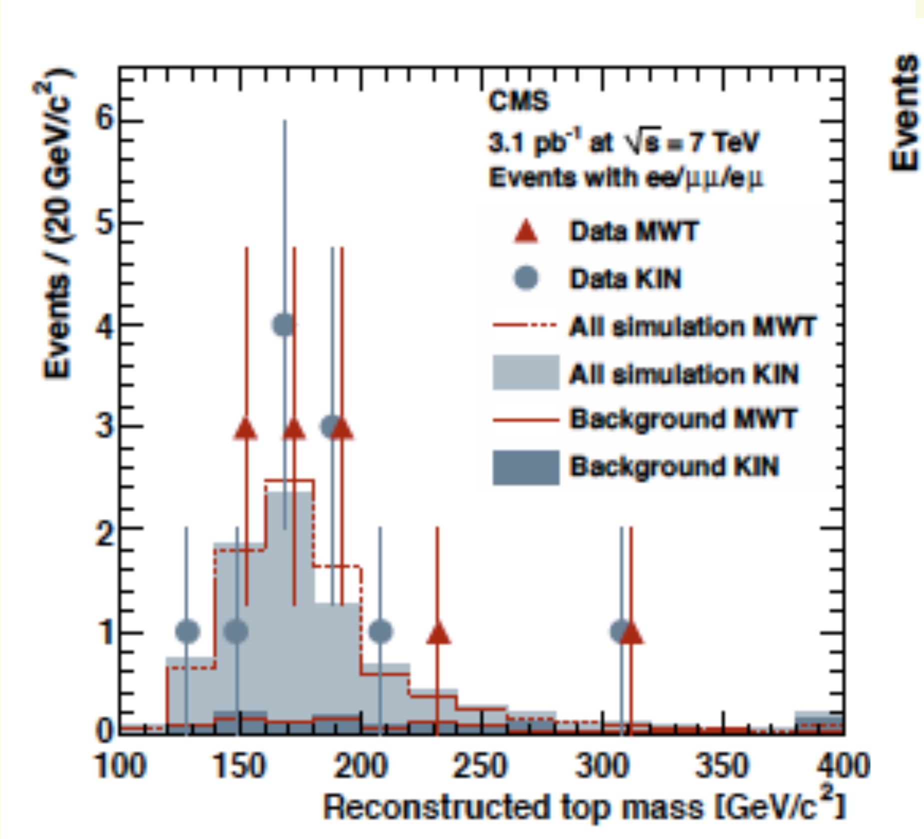
Acceptance is 23 %

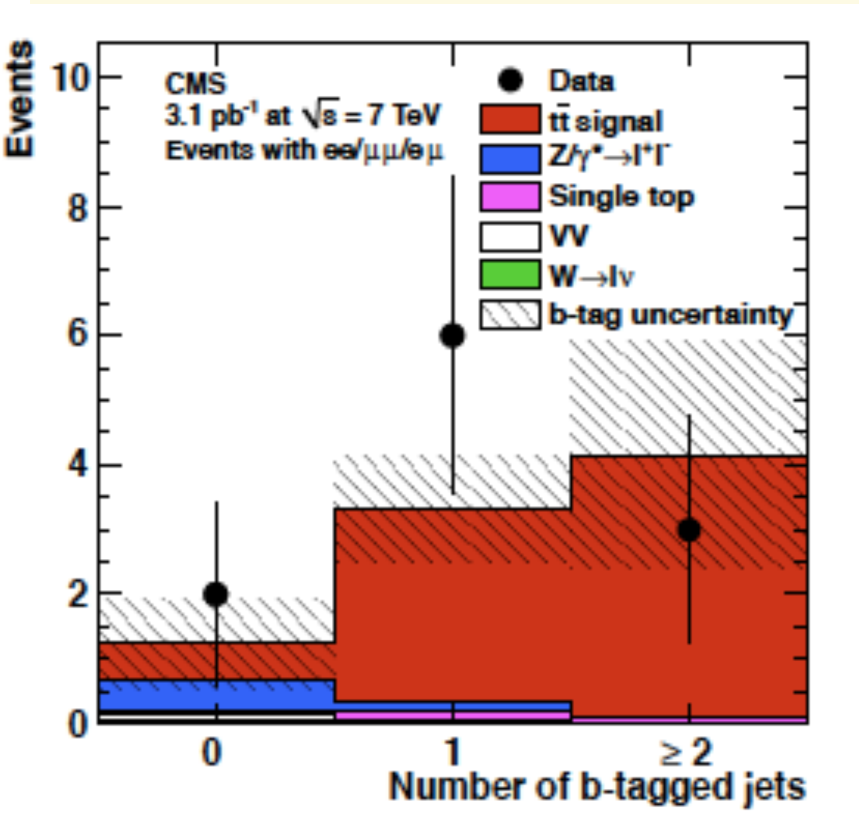
Source	Number of events
Expected $t\bar{t}$	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
Drell-Yan $Z/\gamma^* \to \tau^+\tau^-$	0.18 ± 0.09
Drell-Yan $Z/\gamma^* \to e^+e^-, \mu^+\mu^-$	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	2.1 ± 1.0
Expected total, including $t\bar{t}$	9.8 ± 1.8
Data	11

$$\sigma(pp \to t\bar{t}) = [194 \pm 72\ (\mathrm{stat.})\ \pm 24\ (\mathrm{sys.})\ \pm 21\ (\mathrm{lum.})]\ \mathrm{pb}$$

Consistent with NLO prediction: 157±24 pb (from MCFM)

$t\bar{t}$ to dileptons



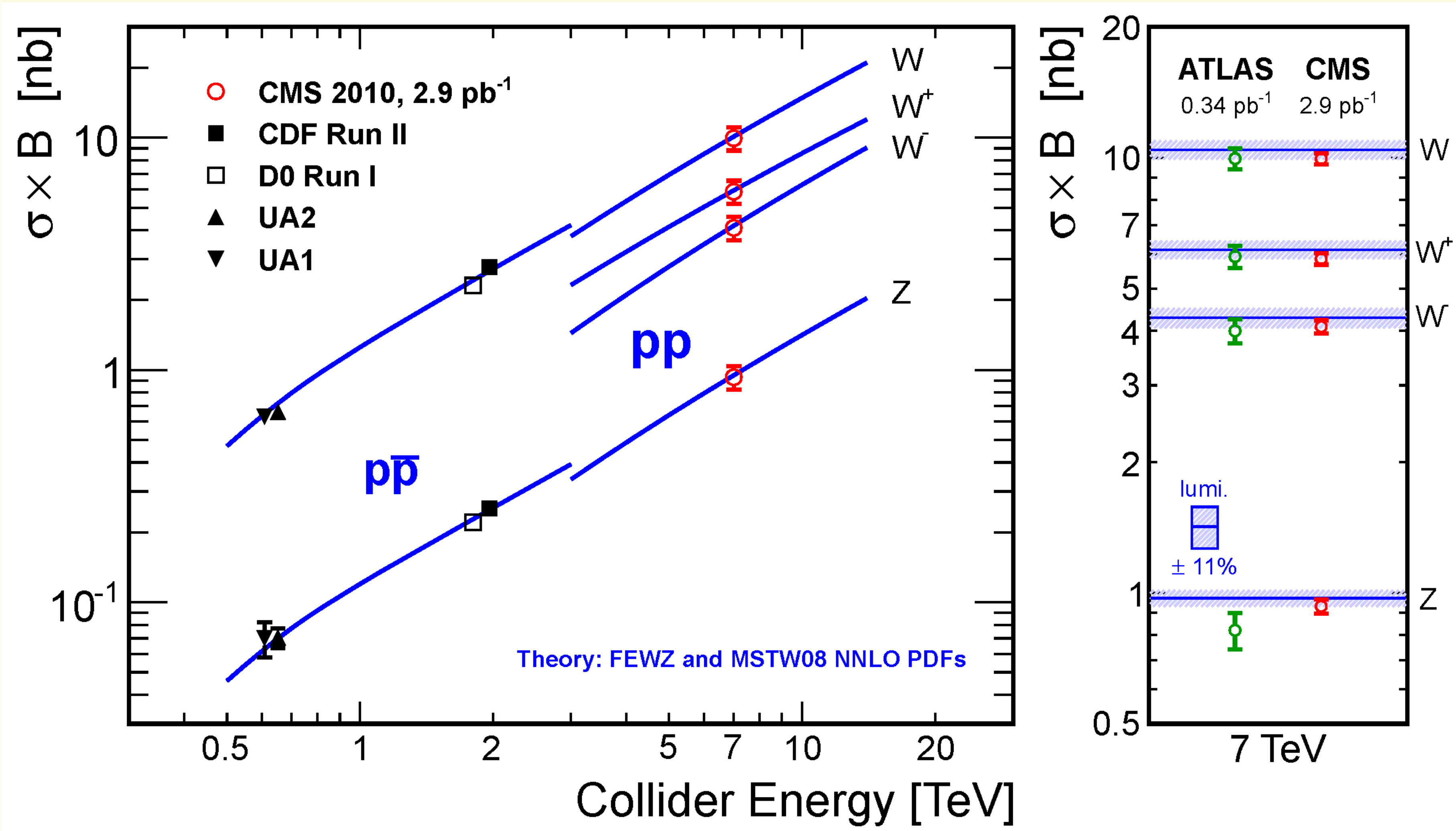


Compatible with prediction of m_t = 172.5 GeV

Significance of impact parameter of track with second highest signifigance
b-tag efficieny: 80%, false positives: 10%

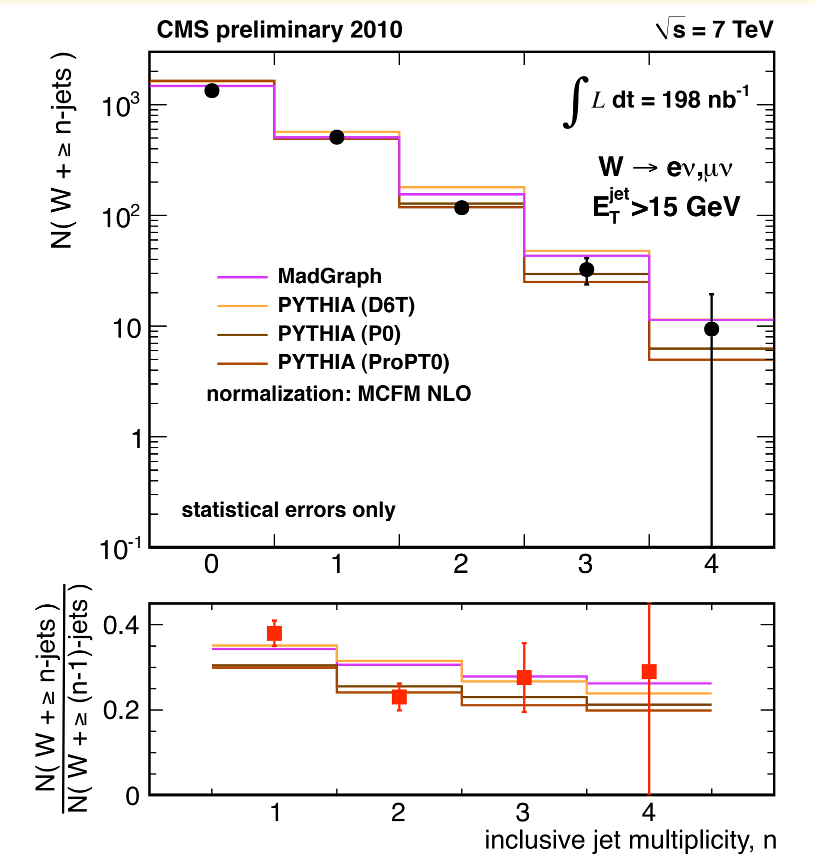
W and Z

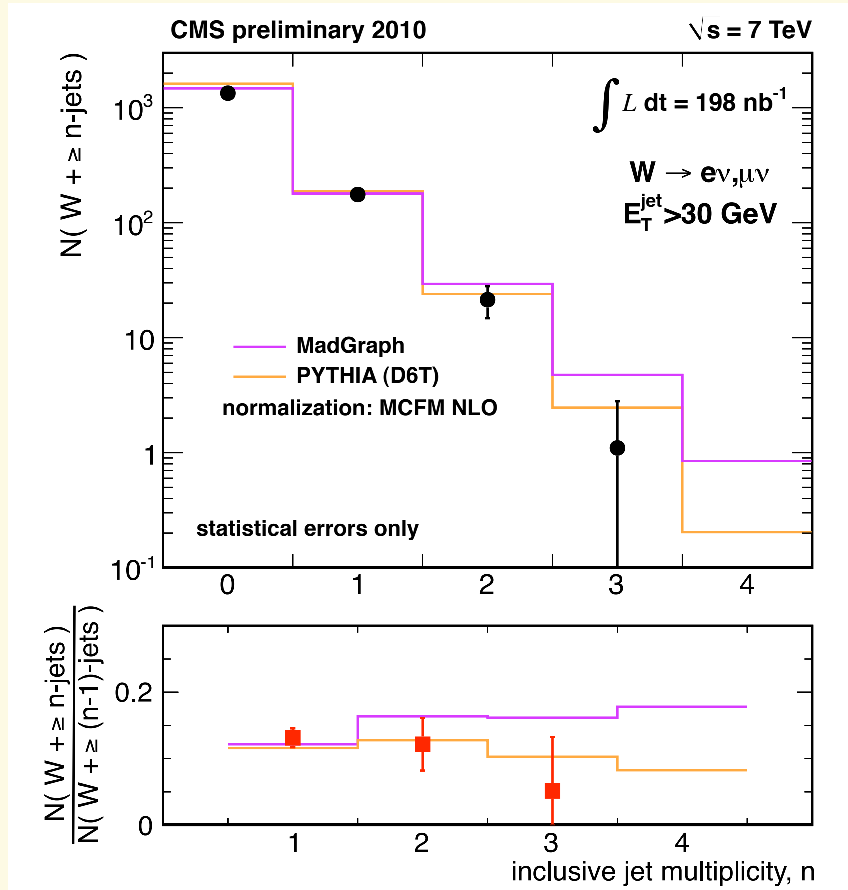
Frighteningly good agreement with NNLO predictions



Differential results: Associated QCD Production

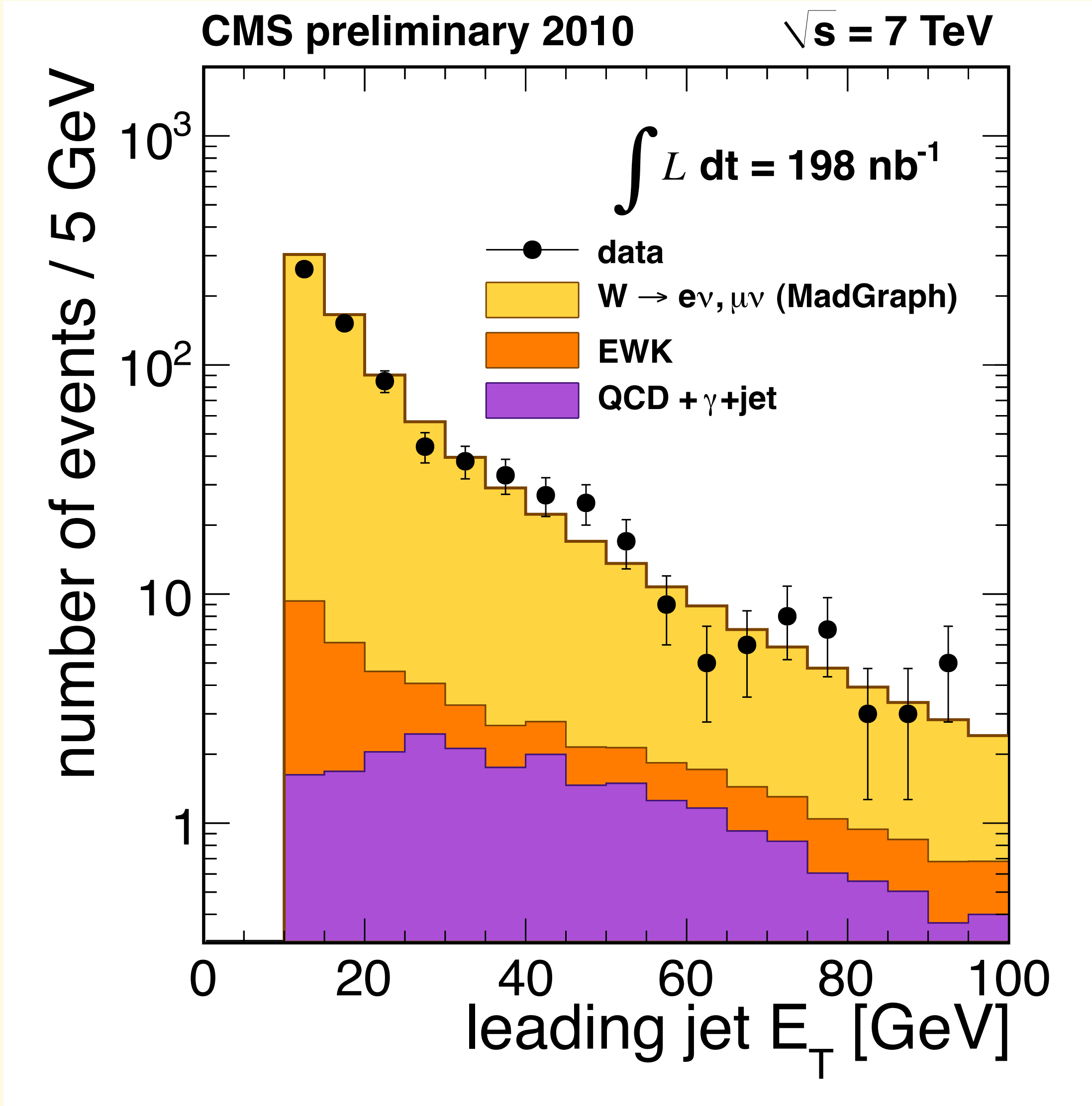
V+Njets Event Rate vs Inclusive Jet Multiplicity N (Patricle Flow Jets) after QCD and EWK BKG (W,Z, top) subtraction from fit to the $M_T(W)$





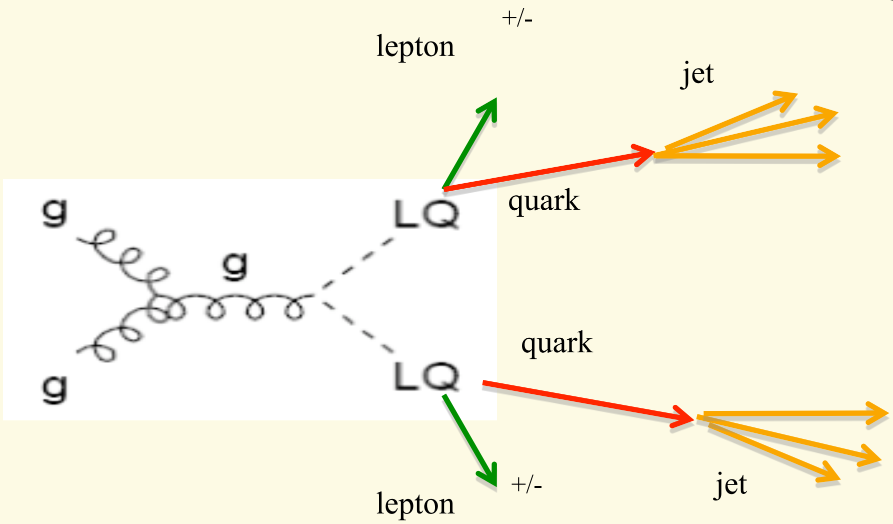
MC Predictions are normalized to NLO MCFM cross sections

Top



CMS preliminary 2010
$\sqrt{s}$ = 7 TeV
$\int L\, dt = 198\ nb^{-1}$
data
$W \rightarrow e\nu, \mu\nu$ (MadGraph)
EWK
QCD + γ+jet
number of events / 5 GeV
leading jet E_T [GeV]

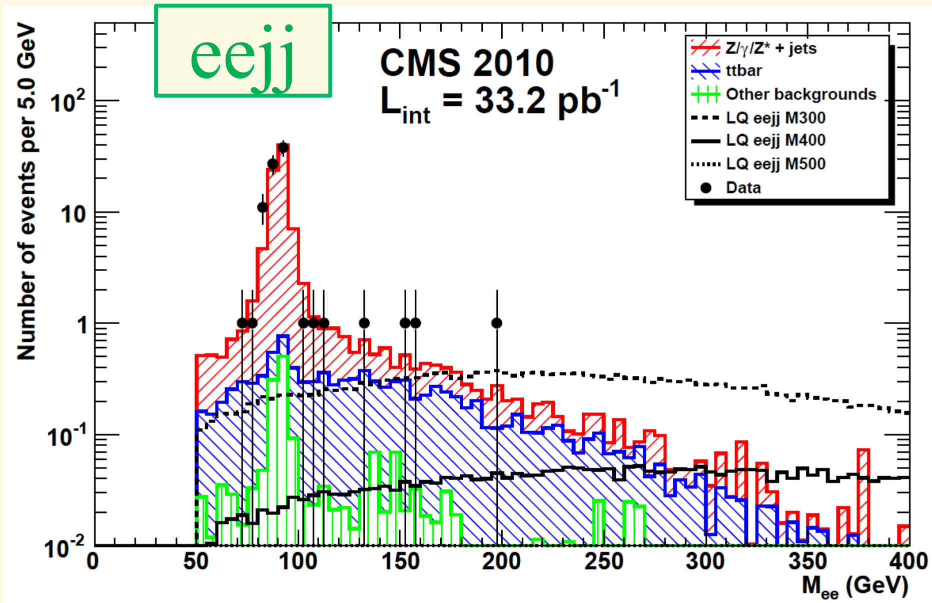
LQ

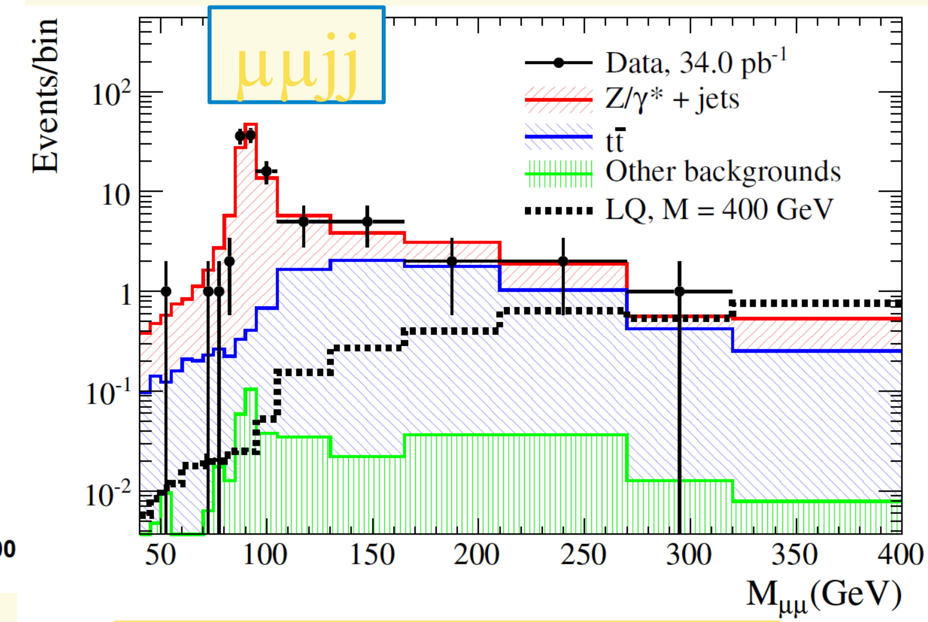


Will have to do until our leptonic SUSY searches come out (very soon!)

- Event selection:
  - At least 2 isolated high-p_T leptons, at least 2 high-p_T jets
  - A lower cut on M_{ll} to remove Z+jets bkg
  - $S_T = p_T(l1) + p_T(l2) + p_T(j1) + p_T(j2) > f(M_{LQ})$

2 leptons, 2 jets

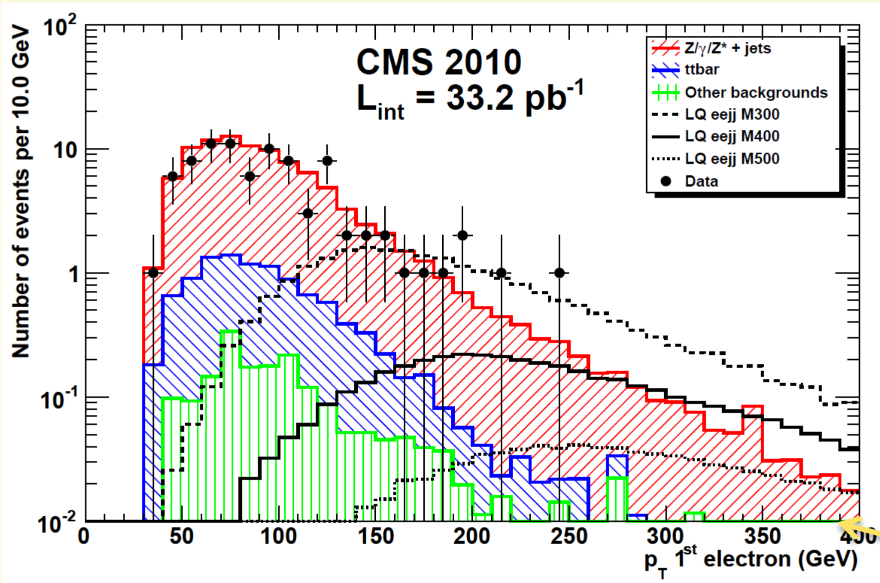


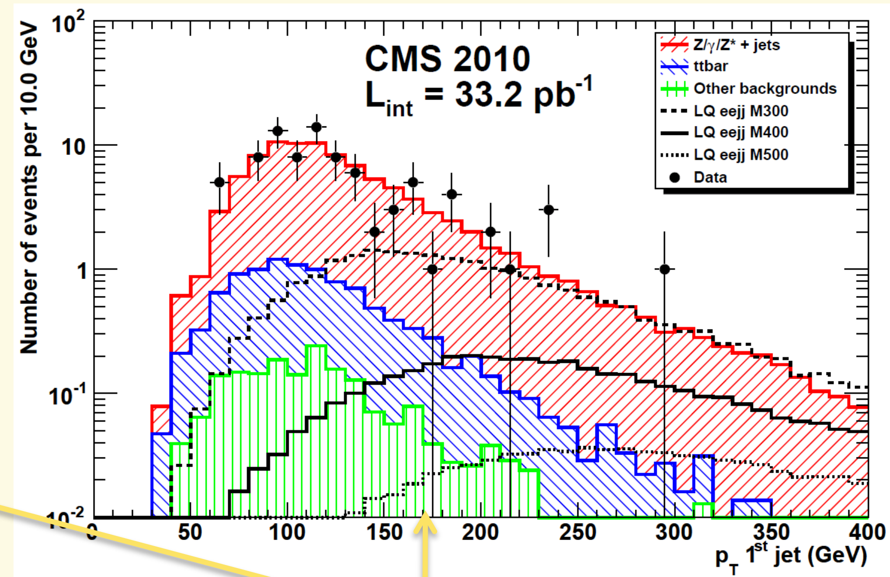


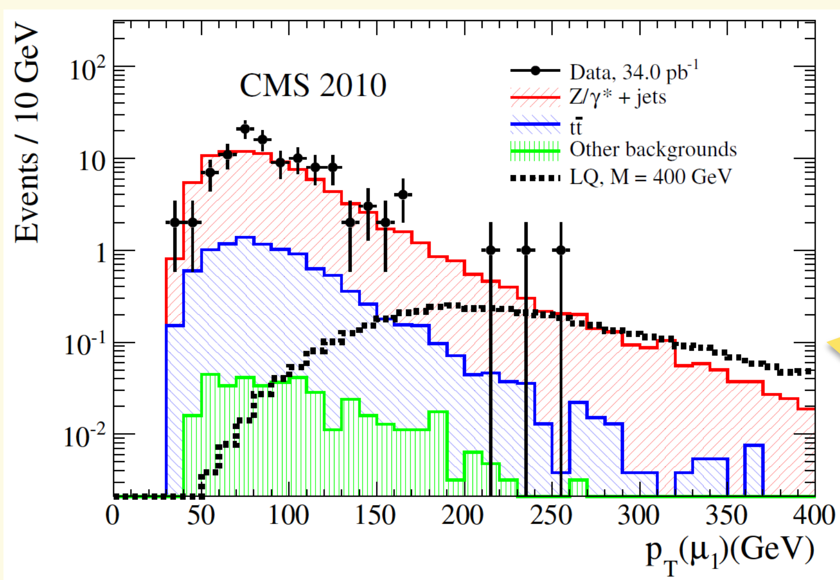
2 electrons P_T>30 GeV, |h|<2.5
2 jets P_T>30 GeV , |h|<3
ΔR(e,j) > 0.7, M_{ee}> 50 GeV, S_T>250 GeV

2 muons P_T>30 GeV, |h|<2.4 (2.1)
2 jets P_T>30 GeV , |h|<3
ΔR(μ, μ) > 0.3, S_T>250 GeV

LQ preselection distributions





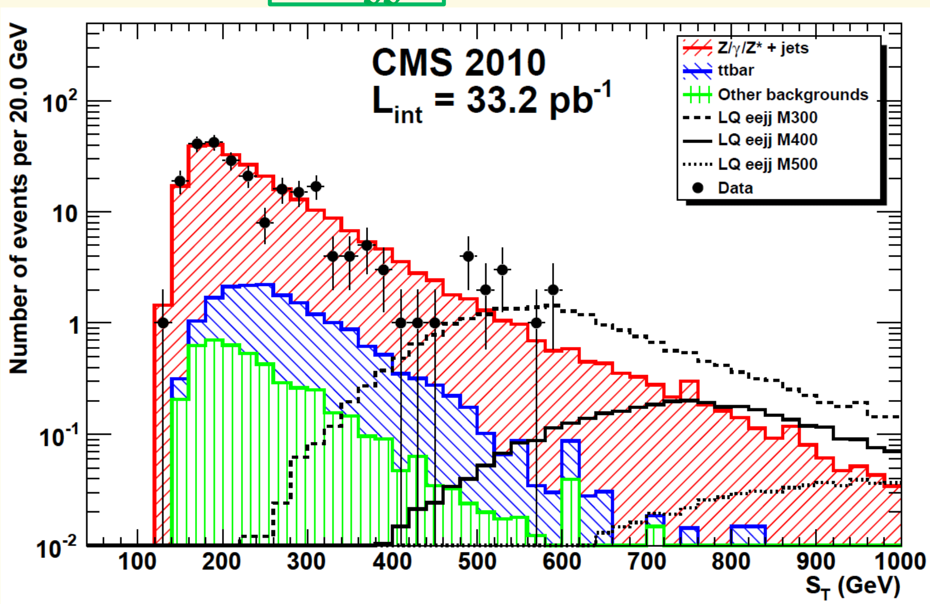


2 electrons P_T>30 GeV, |h|<2.5
2 jets P_T>30 GeV , |h|<3
ΔR(e,j) > 0.7, M_{ee}> 50 GeV,
S_T>250 GeV

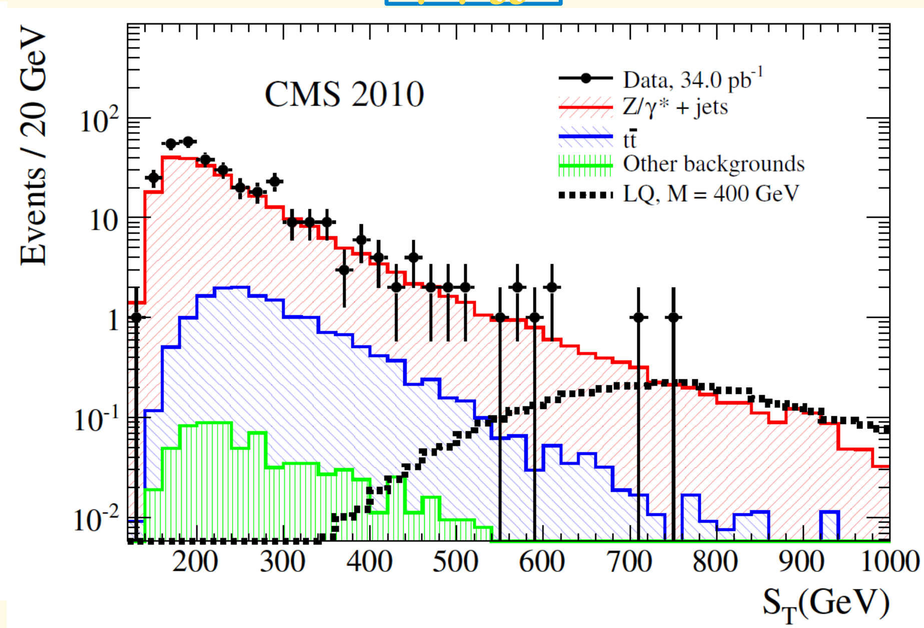
2 muons P_T>30 GeV, |h|<2.4 (2.1)
2 jets P_T>30 GeV , |h|<3
ΔR(μ, μ) > 0.3 , $M_{\mu\mu}$>50 GeV,
S_T>250 GeV

S_T

eejj



μμjj

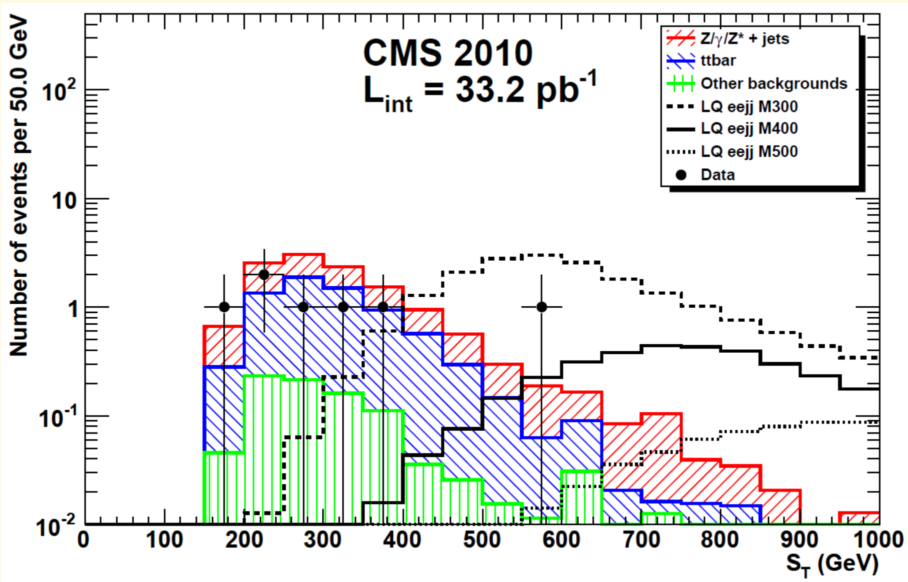


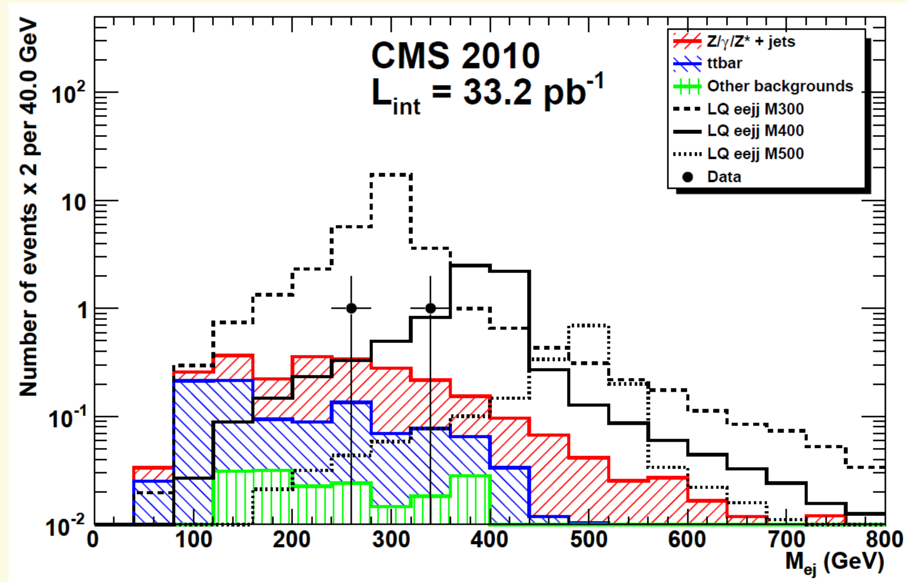
2 electrons P_T>30 GeV, |h|<2.5
2 jets P_T>30 GeV , |h|<3
$\Delta R(e,j) > 0.7$, M_{ee}> 50 GeV,
S_T>250 GeV (but not applied in this plot)

2 muons P_T>30 GeV, |h|<2.4 (2.1)
2 jets P_T>30 GeV , |h|<3
$\Delta R(\mu, \mu) > 0.3$, $M_{\mu\mu}$>50 GeV
S_T>250 GeV (but not applied in this plot)

S_T = scalar sum of the pT of the 2 selected leptons and 2 selected jets

Final Selection: eejj

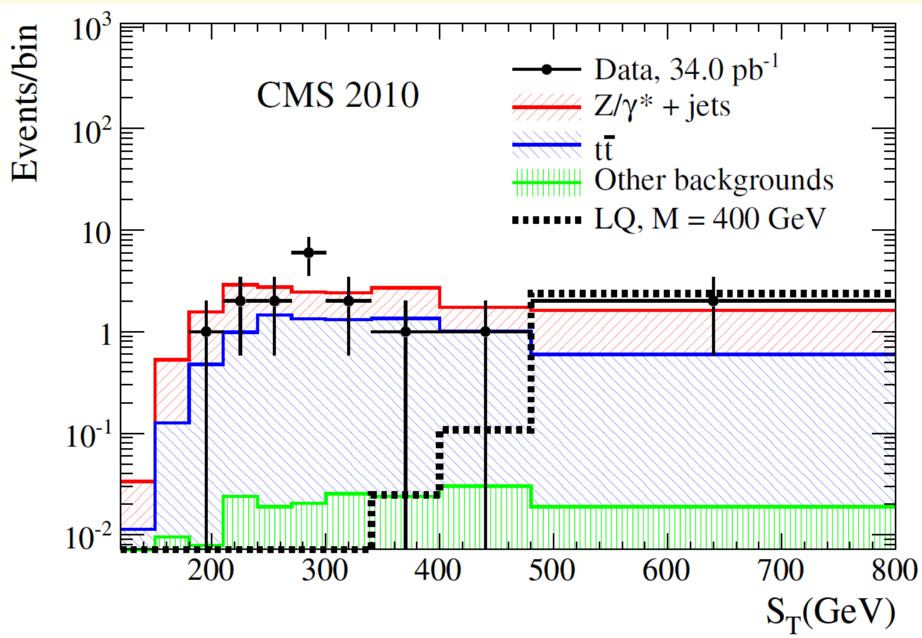


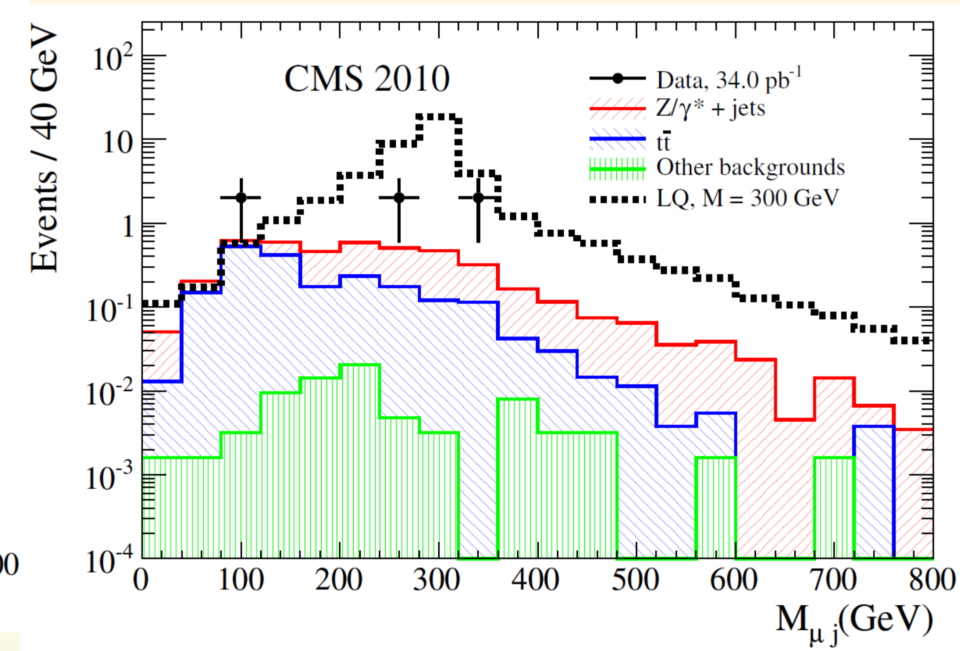


2 electrons P_T>30 GeV, |h|<2.5; 2 jets P_T>30 GeV, |h|<3; ΔR(e,j)>0.7; M_{ee}> 125 GeV; S_T>f (M_{LQ})

M_{LQ} (S_T Request) [GeV]	MC Signal Samples Selected Events	Acceptance ×Efficiency	Monte Carlo Background Samples Selected Events in $t\bar{t}$ + jets	Z/γ + jets	Others	All	Events in Data
250 (S_T >400)	43.8±0.2	0.380±0.002	1.1 ±0.06	1.3 ±0.1	0.14±0.02	2.5 ±0.1	1
300 (S_T >470)	17.3±0.1	0.430±0.002	0.44±0.04	0.75±0.07	0.10±0.02	1.3 ±0.1	1
340 (S_T >510)	8.88±0.04	0.469±0.002	0.27±0.03	0.56±0.06	0.08±0.02	0.91±0.08	1
400 (S_T >560)	3.55±0.02	0.522±0.002	0.17±0.02	0.41±0.05	0.06±0.02	0.63±0.06	1
450 (S_T >620)	1.70±0.01	0.539±0.002	0.10±0.02	0.28±0.05	0.02±0.01	0.41±0.06	0

Final Selection: μμjj



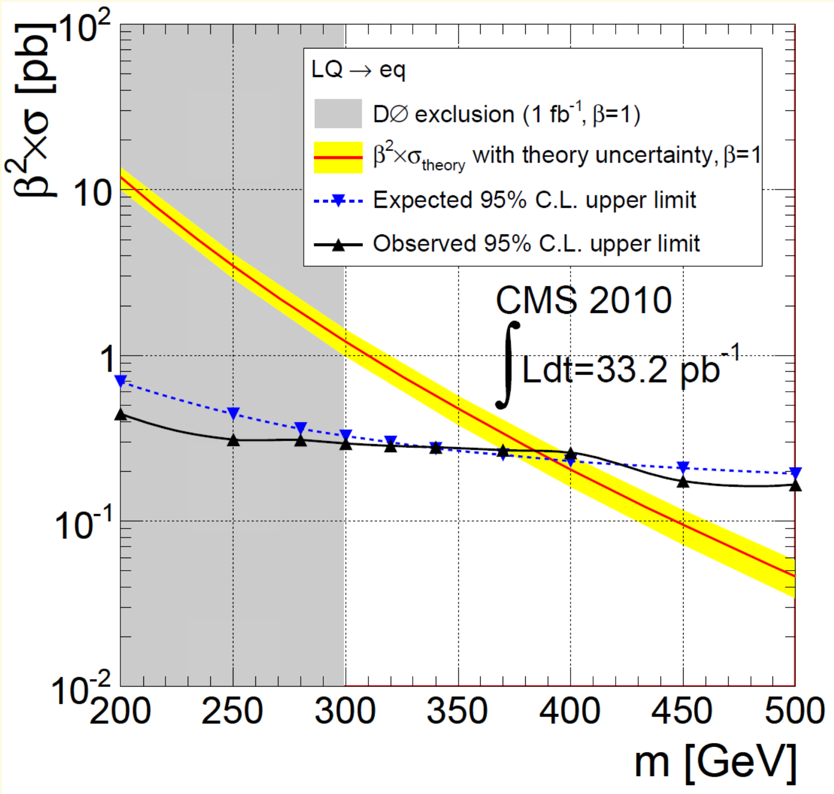


$M_{\mu j}$ = muon-jet inv. mass (2 entries/event). Of the 2 ways to combine 2 muons and 2 jets – the combination with minimum mass difference is chosen

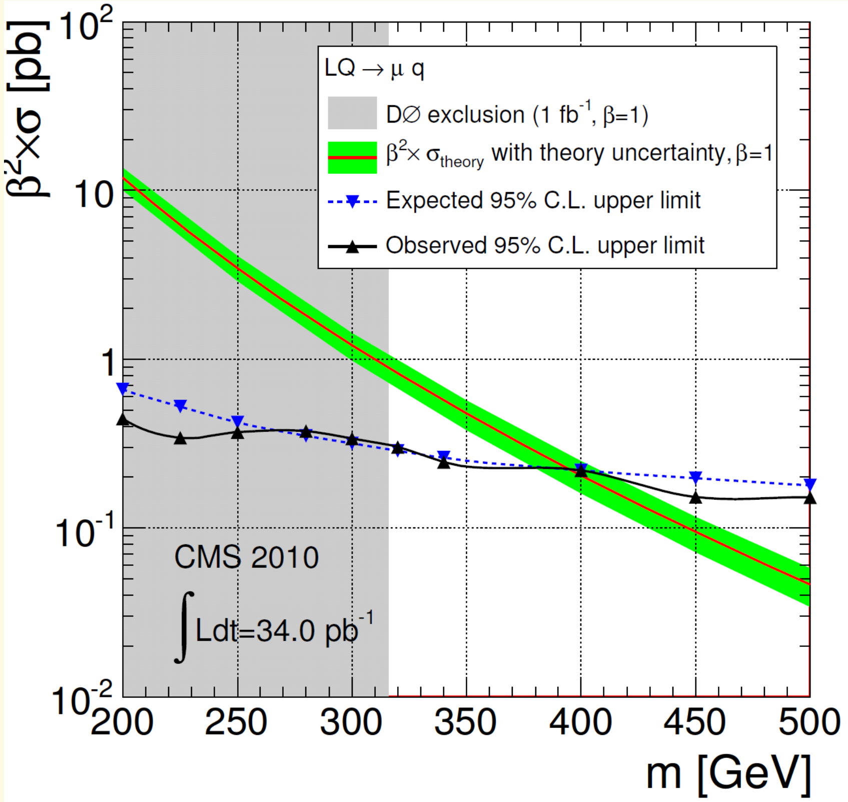
2 muons P_T>30 GeV, |h|<2.4(2.1); ΔR(μ, μ)>0.3; 2 jets P_T>30 GeV, |h|<3; $M_{\mu\mu}$>115 GeV; S_T>f(M_{LQ})

M_{LQ}	S_T	Z/γ^*+jets	$t\bar{t}$	Other Bkg	All Bkg	Data	S	ϵ_S
250	400	1.92 ± 0.03	1.60 ± 0.08	0.05 ± 0.01	3.57 ± 0.09	3	51.5 ± 5.2	0.437 ± 0.003
300	449	1.53 ± 0.03	0.98 ± 0.06	0.04 ± 0.01	2.54 ± 0.07	3	21.3 ± 2.1	0.518 ± 0.004
340	530	0.79 ± 0.01	0.34 ± 0.04	0.01 ± 0.00	1.14 ± 0.04	1	9.8 ± 1.0	0.508 ± 0.003
400	560	0.67 ± 0.01	0.27 ± 0.03	0.01 ± 0.00	0.94 ± 0.03	1	4.0 ± 0.4	0.578 ± 0.004
450	620	0.49 ± 0.01	0.16 ± 0.02	0.01 ± 0.00	0.66 ± 0.03	0	1.9 ± 0.2	0.600 ± 0.004

LQ Limits



LQ → eq
DØ exclusion (1 fb^{-1}, β=1)
$\beta^2\times\sigma_{theory}$ with theory uncertainty, β=1
Expected 95% C.L. upper limit
Observed 95% C.L. upper limit
CMS 2010
$\int$Ldt=33.2 pb^{-1}
$\beta^2\times\sigma$ [pb]
m [GeV]

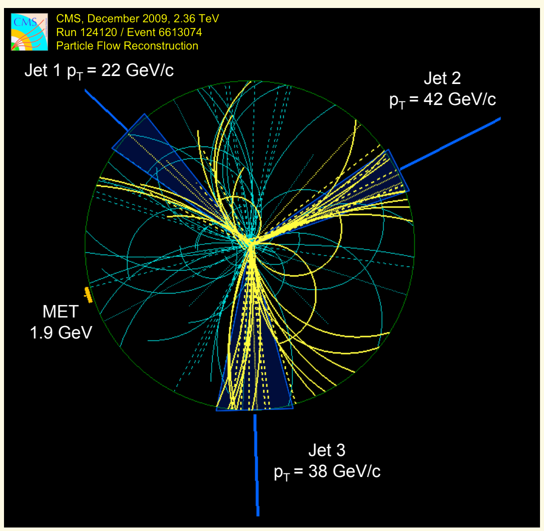


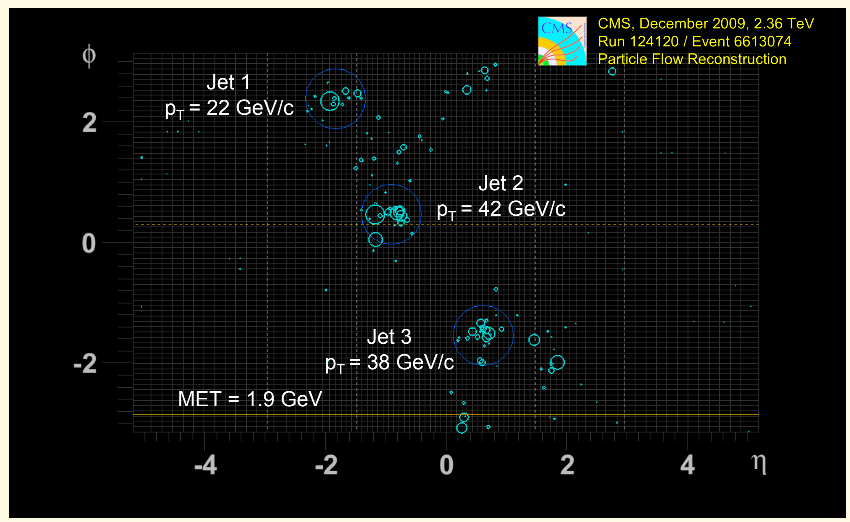
LQ → μ q
DØ exclusion (1 fb^{-1}, β=1)
$\beta^2\times\sigma_{theory}$ with theory uncertainty, β=1
Expected 95% C.L. upper limit
Observed 95% C.L. upper limit
CMS 2010
$\int$Ldt=34.0 pb^{-1}
$\beta^2\times\sigma$ [pb]
m [GeV]

Particle flow

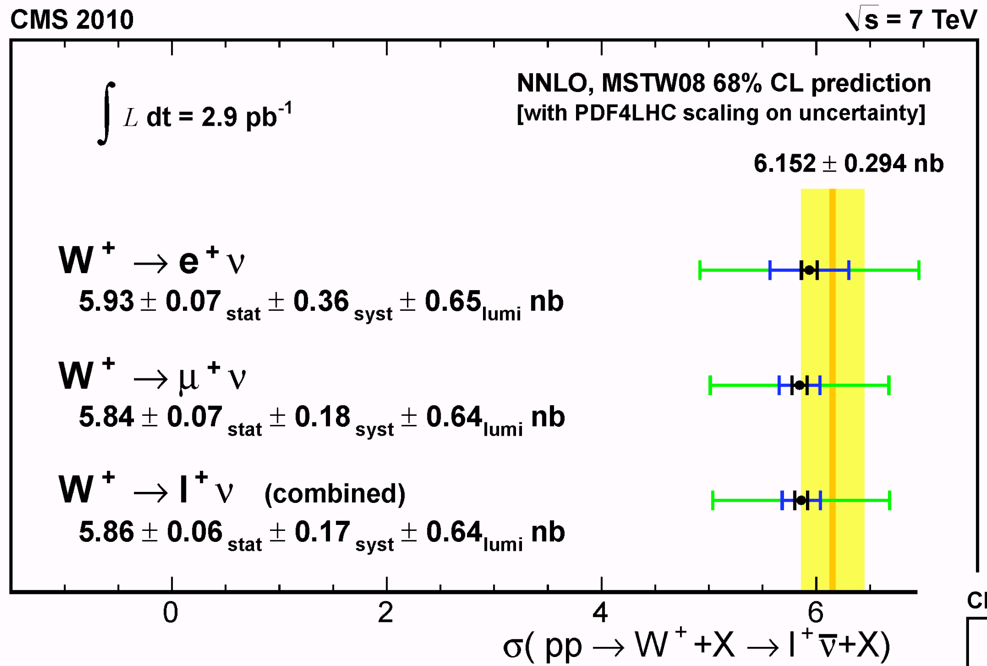
PFT-09-001 for real algorithm. Impressionistic version below:

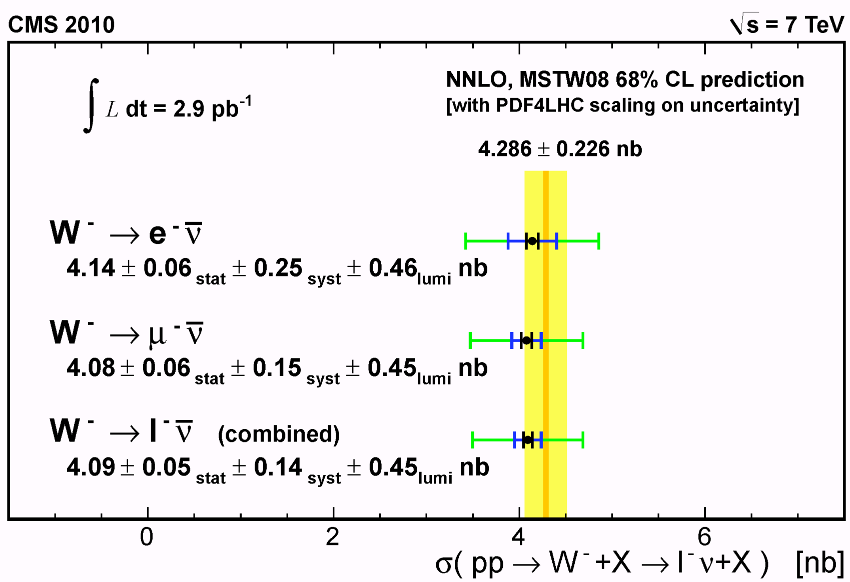
- clusters are formed (except in HF) for local energy maxima ("seeds") in each of the calorimeters and the preshower separately.
- elements are clusters, tracks, and local muons.
- pairs of elements are linked. The linking process includes a brem recovery algorithm. Elements with common links are "blocks" (usually containing only 1,2, or 3 clusters/tracks/muons).
- electrons, photons, muons, charged hadrons and neutral hadrons are reconstructed from the blocks
  - muons and electrons are identified and removed from the block first
  - if more than one ecal clusters is associated with a track, they are kept (in pT order) as long as the total energy sum is less than the track momentum)
  - if the energies of the linked clusters are larger than the track momentum by its uncertainty, the excess is given to photons or possibly a photon and a neutral hadron,
  - charged hadron energy determined by resolution-weighted average of track and calorimeter energies



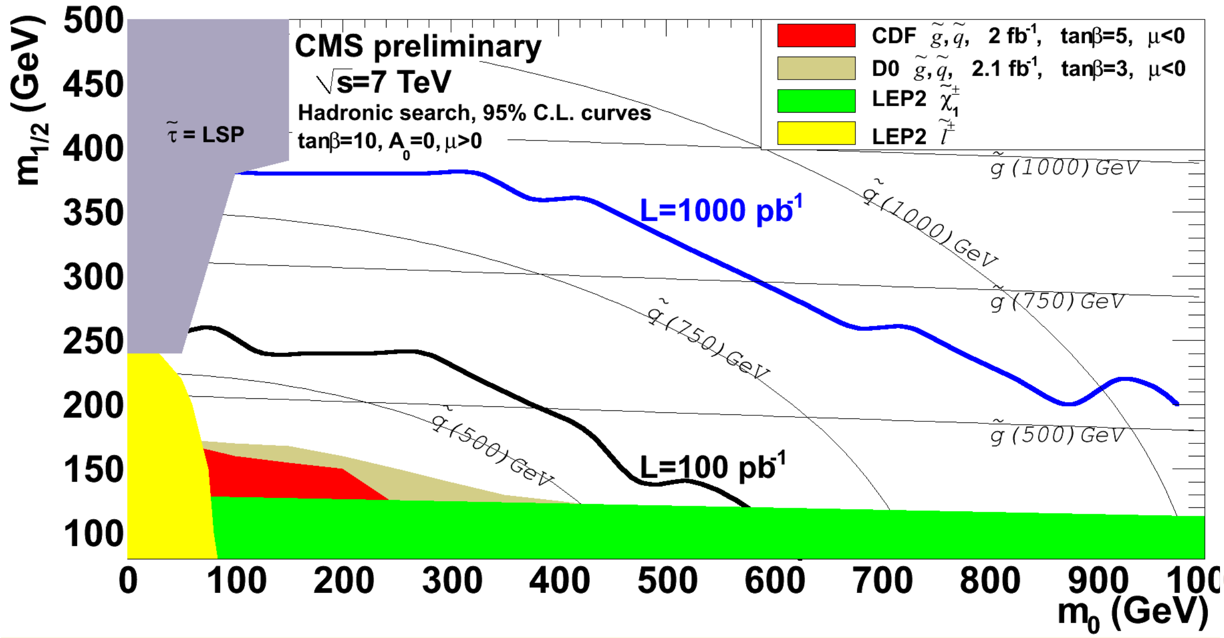


Cross section results by charge



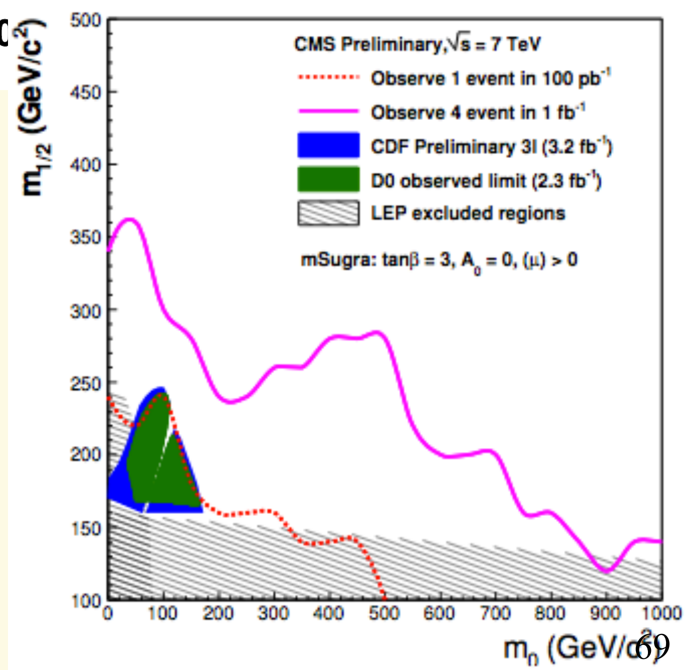


Prospects

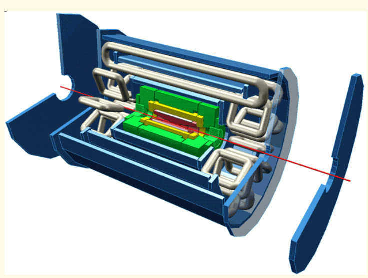


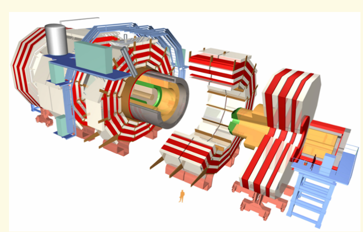
95% C.L. exclusion limits for mSUGRA searches in all-hadronic channels

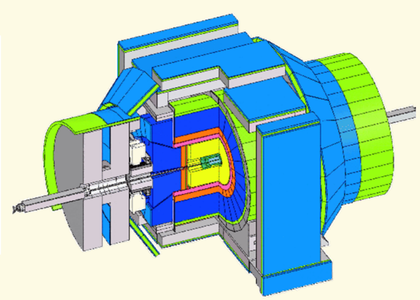
mSUGRA exclusion limits in the like-sign dilepton channels

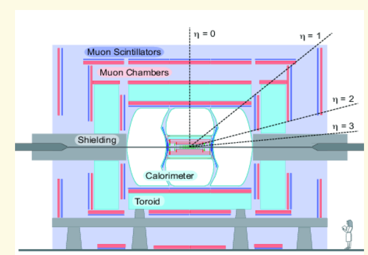


	ATLAS	CMS	CDF II	D0 II
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T endcap)	4 T solenoid + return yoke	1.4T	2T + toroid (1.8T)
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5\text{x}10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5\text{x}10^{-4} p_T + 0.005$	Si strips and drift chamber	Si strips + scintillating fiber
EM calorimeter	Pb+LAr $\sigma/E \approx 10\%/\sqrt{E} + 0.007$	PbWO4 crystals $\sigma/E \approx 3\%/\sqrt{E} + 0.003$	Lead-scintillator $\sigma/E \approx 13.5\%/\sqrt{E} + 0.015$ GeV in barrel	U+LAr
Hadronic calorimeter	Fe+scint. / Cu+LAr (10λ) $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV	Brass+scintillator (7 λ + catcher) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV	Iron-scintillator $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV in barrel	U+Lar (Cu or stainless in outer hadronic)
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV (ID +MS)	$\sigma/p_T \approx 1\%$ @ 50GeV to 10% @ 1TeV (DT/ CSC+Tracker)	Rapidities to 1.4	Rapidities to 2.0









Noise

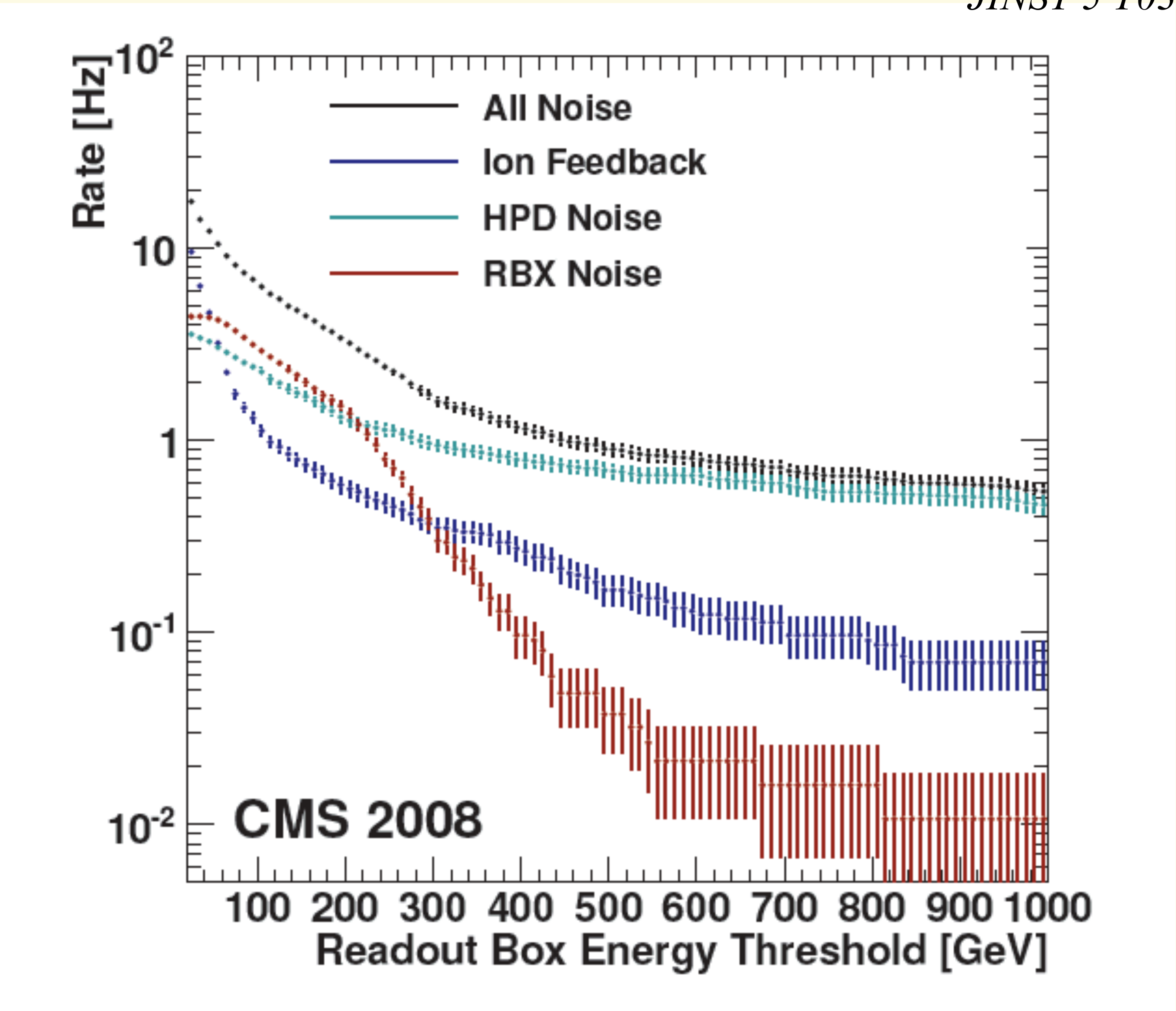
Ion Feedback. HCAL HPDs occasionally generate appreciable signals even when no light is incident on their photo-cathodes. Such signals are predominantly caused by a thermally emitted electron ionizing a gas or surface molecule in the acceleration gap of the HPD. That ion is accelerated back to the cathode and liberates further electrons, causing a signal equivalent to many photo-electrons. This behavior typically manifests as a significant energy deposit within one to three channels of a given HPD within a single event.

HPD Noise. It is known that the presence of an external magnetic field can alter the flashover voltage of dielectric materials (see reference [4]). Misalignments between the electric field within an HPD and the external solenoid field can lower the flashover voltage of the HPD. This can lead to an avalanche of secondary electrons, producing significant energy deposition in a large number of channels within an HPD. However, large energy deposits in multiple HPD channels have been observed even with the solenoid field off, and the source of these deposits is still under investigation. Signals appearing in a large number of channels within a single HPD, regardless of the state of the magnetic field, are categorized under the heading “HPD noise”.

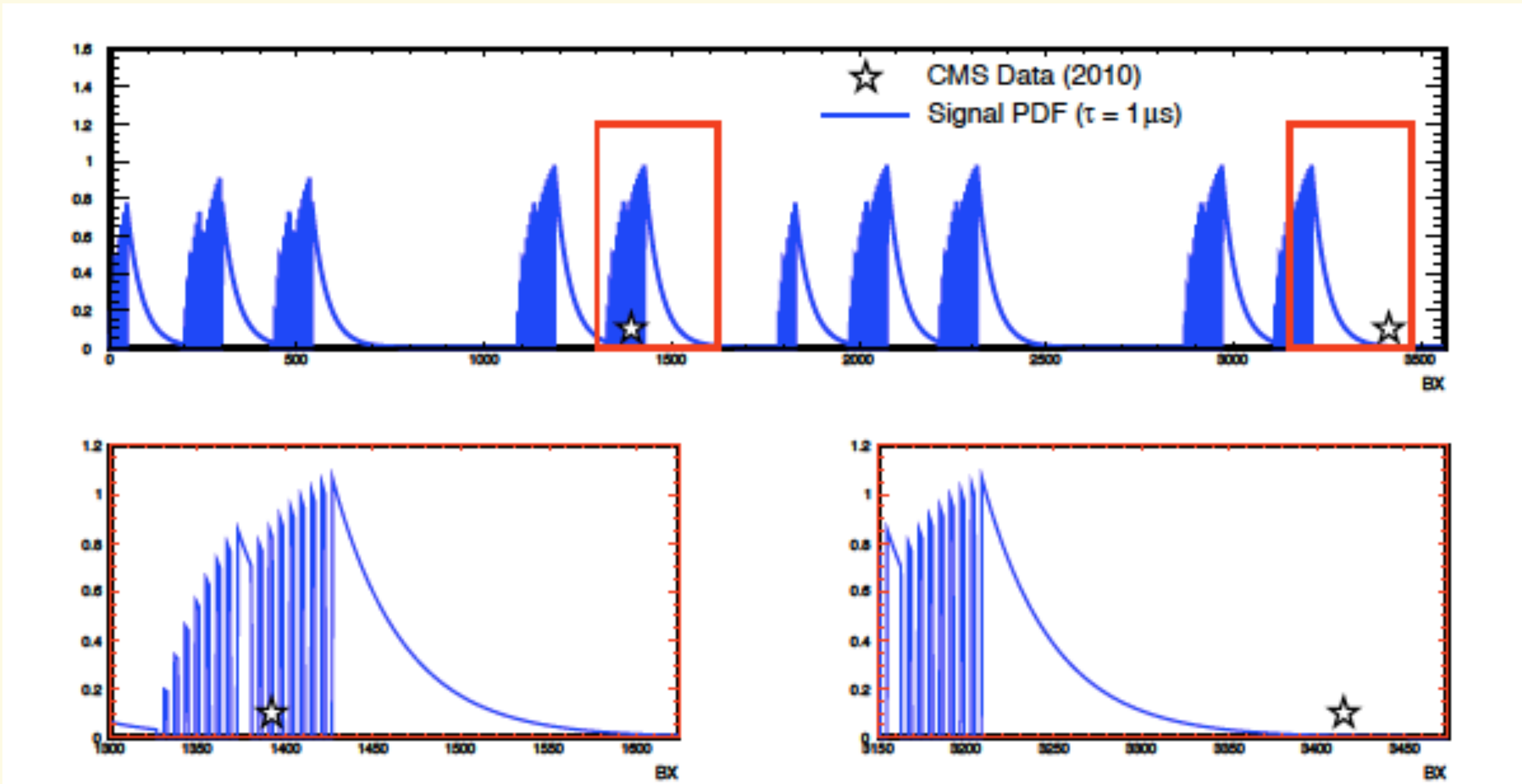
RBX Noise. Events have been observed in which nearly all of the 72 channels within a single HB or HE RBX report large observed energies. Though the cause of this is not yet well understood, its distinctive signature allows it to be easily identified within an event.

HCAL Noise

CFT-09-019
JINST 5 T03014



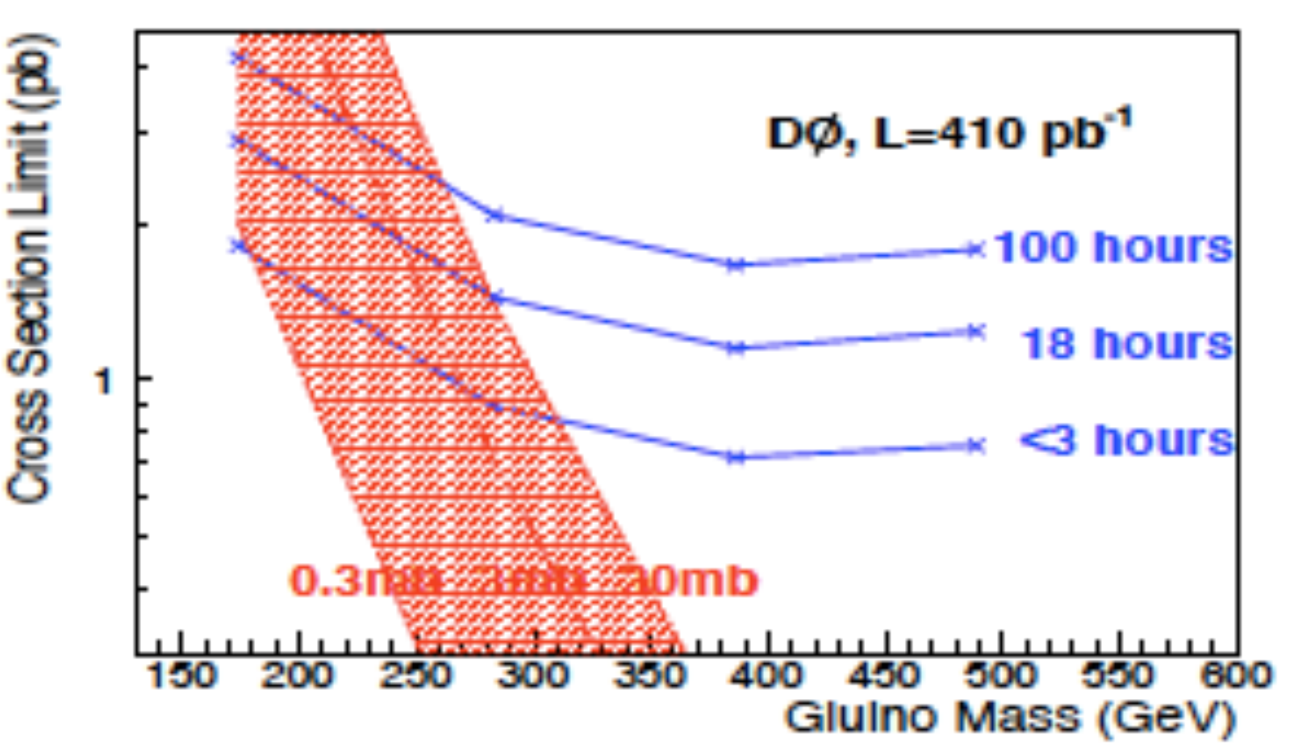
Stopped rhadron: fit to time



D0

Compare our EM only to their 0.3 mb result (180 GeV)

This is the first search for exotic, out-of-time hadronic energy deposits at a high-energy collider. The results from 410 pb^{-1} of Tevatron data are able to exclude a cross section of $\sim$1 pb for gluinos stopping in the D0 calorimeter and later decaying into a gluon and neutralino. For a $\tilde{\chi}_1^0$ mass of 50 GeV, we are able to exclude $M_{\tilde{g}}$<270 GeV, assuming a 100% branching fraction for $\tilde{g}\rightarrow g\tilde{\chi}_1^0$, a gluino lifetime less than 3 hours, and a neutral cross section of 3 mb.

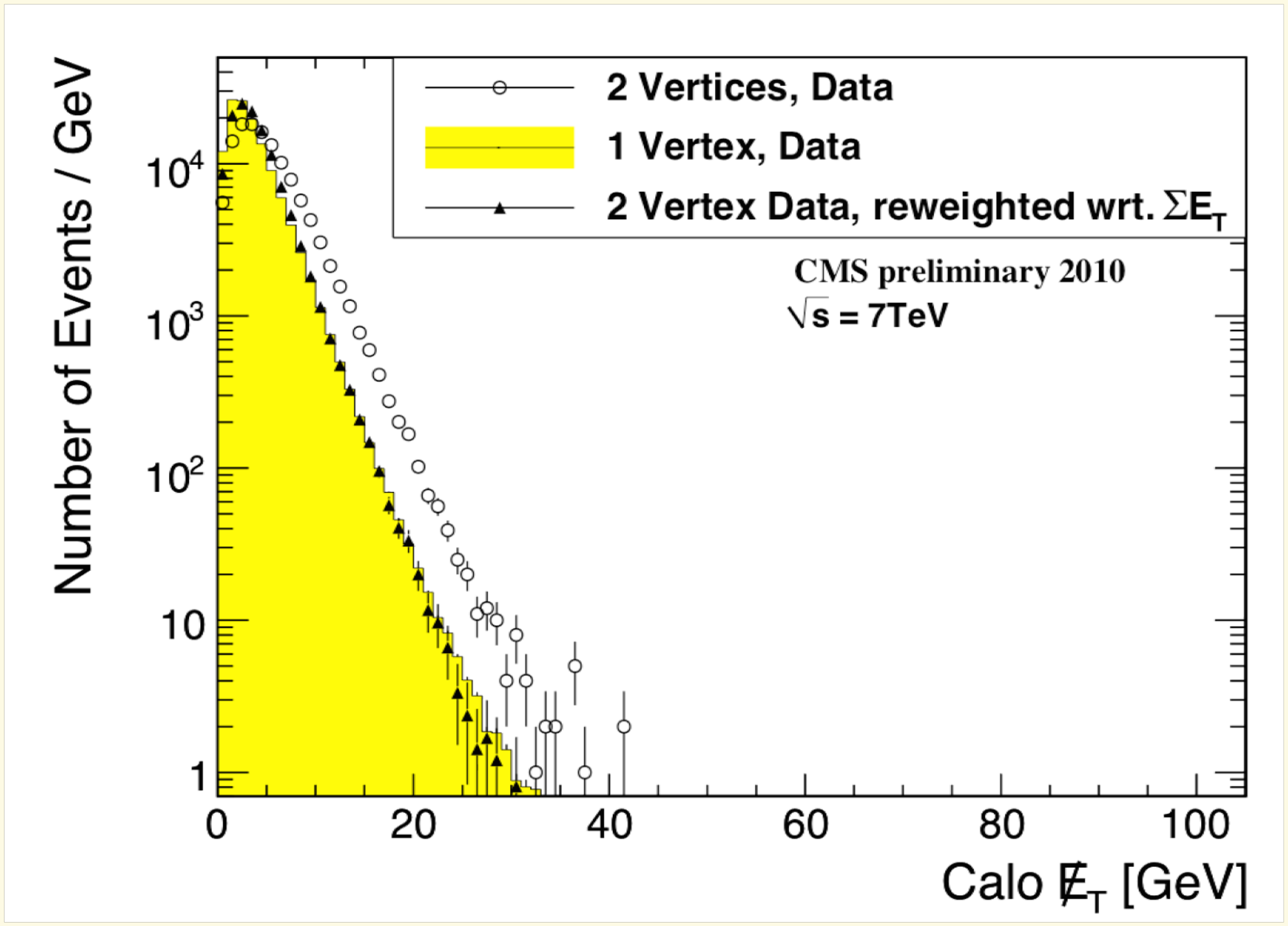


$$\alpha_T = \frac{1}{2}\frac{1-\Delta H_T}{\sqrt{1-(\not{H}_T / H_T)^2}}$$

if $\Delta \mathrm{H}_T$ is zero

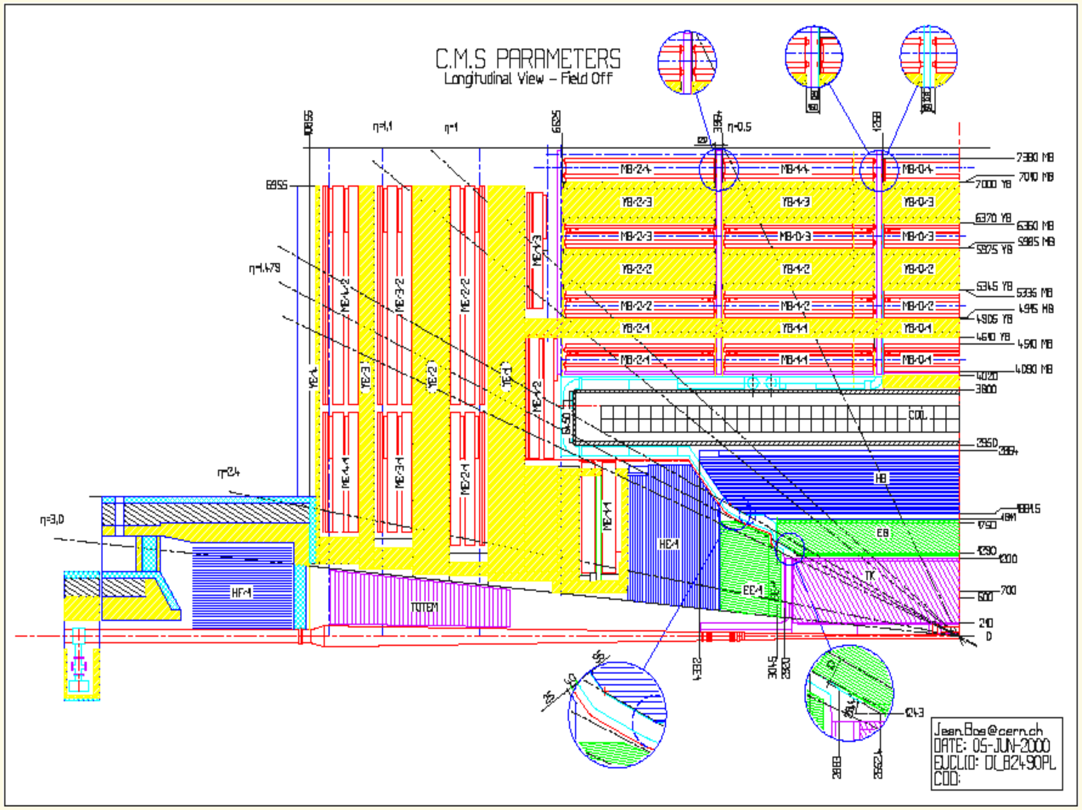
$$\not{H}_T / H_T = \sqrt{1-\left(\frac{1}{2\alpha_T}\right)^2}$$

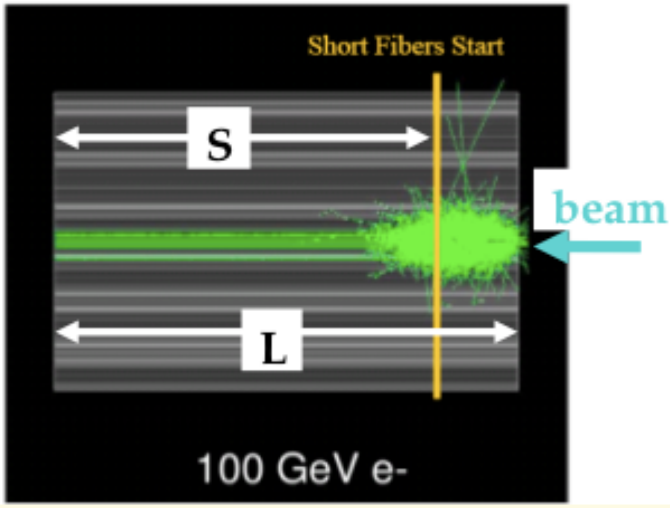
pileup



Number of Events / GeV
10^4
10^3
10^2
10
1
0
20
40
60
80
100
Calo $\not\!\!E_T$ [GeV]
2 Vertices, Data
1 Vertex, Data
2 Vertex Data, reweighted wrt. ΣE_T
CMS preliminary 2010
$\sqrt{s}$ = 7TeV

HF

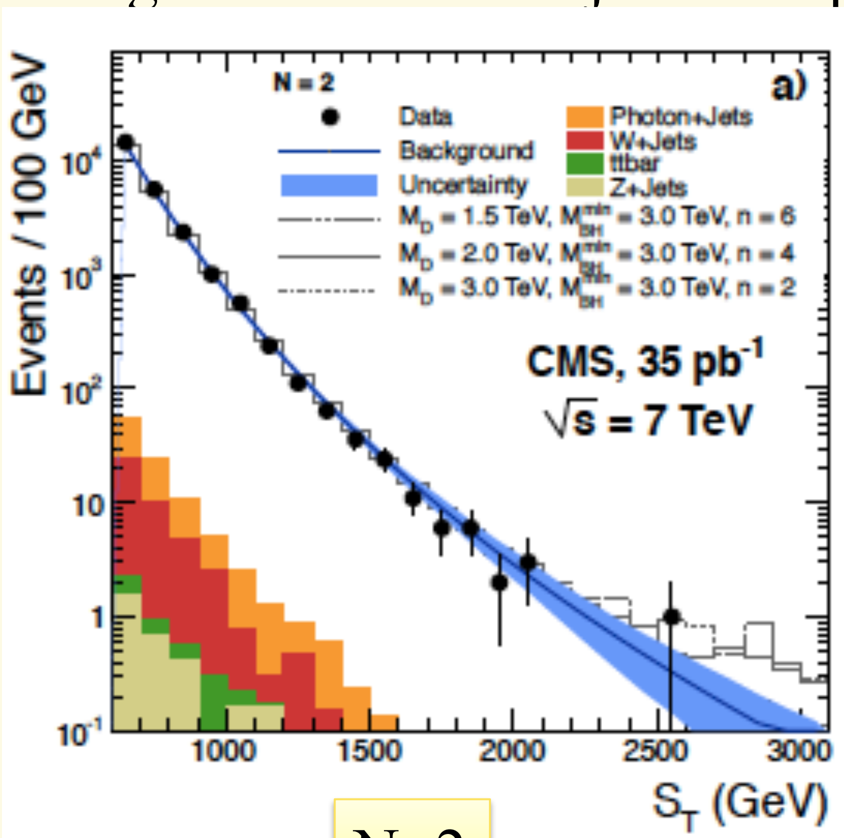

C.M.S PARAMETERS
Longitudinal View – Field Off
Jean.Bos@cern.ch
DATE: 05-JUN-2000


Short Fibers Start
S
beam
L
100 GeV e-

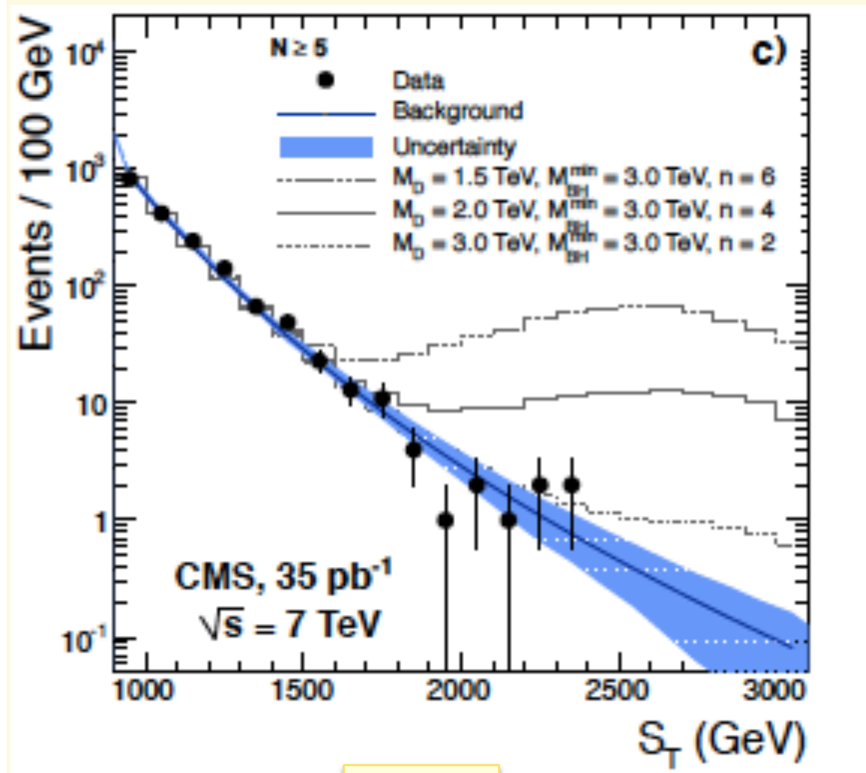
Black Hole Search

arXiv: 1012.335

Predict H_T distribution at high object multiplicity (N=3,4,5) using that with low object multiplicity (N=2,3)



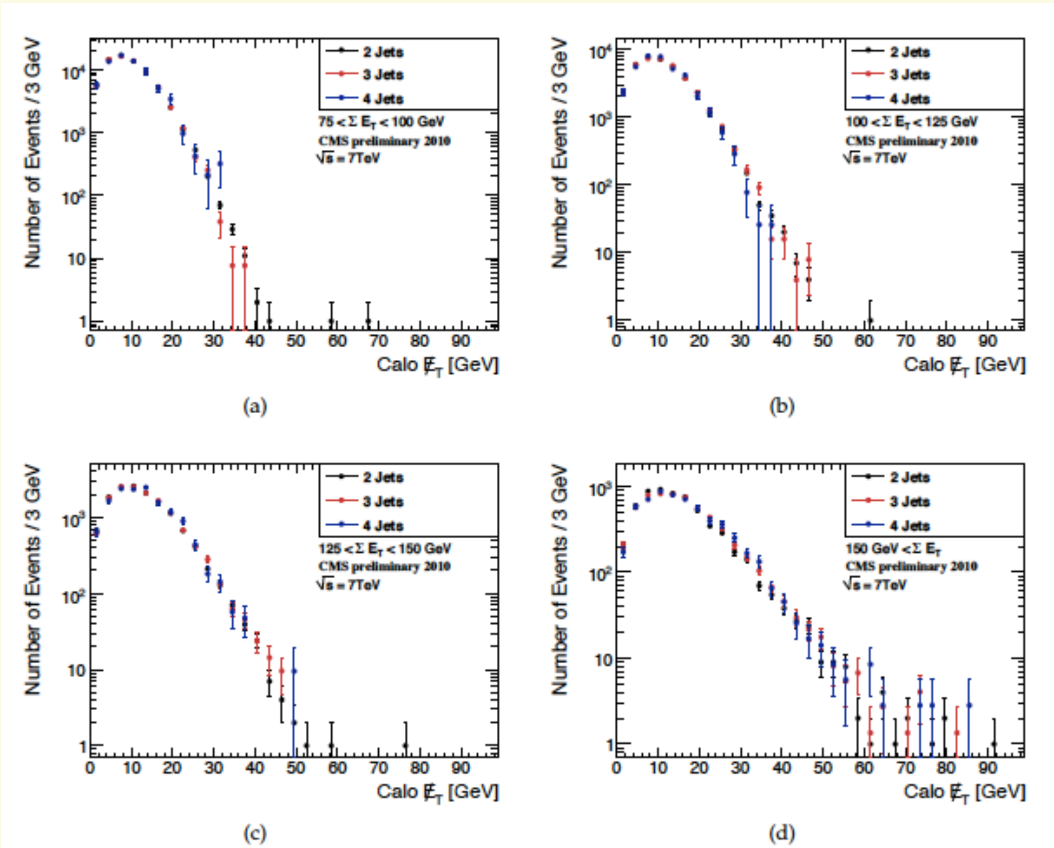
N=2



N=5

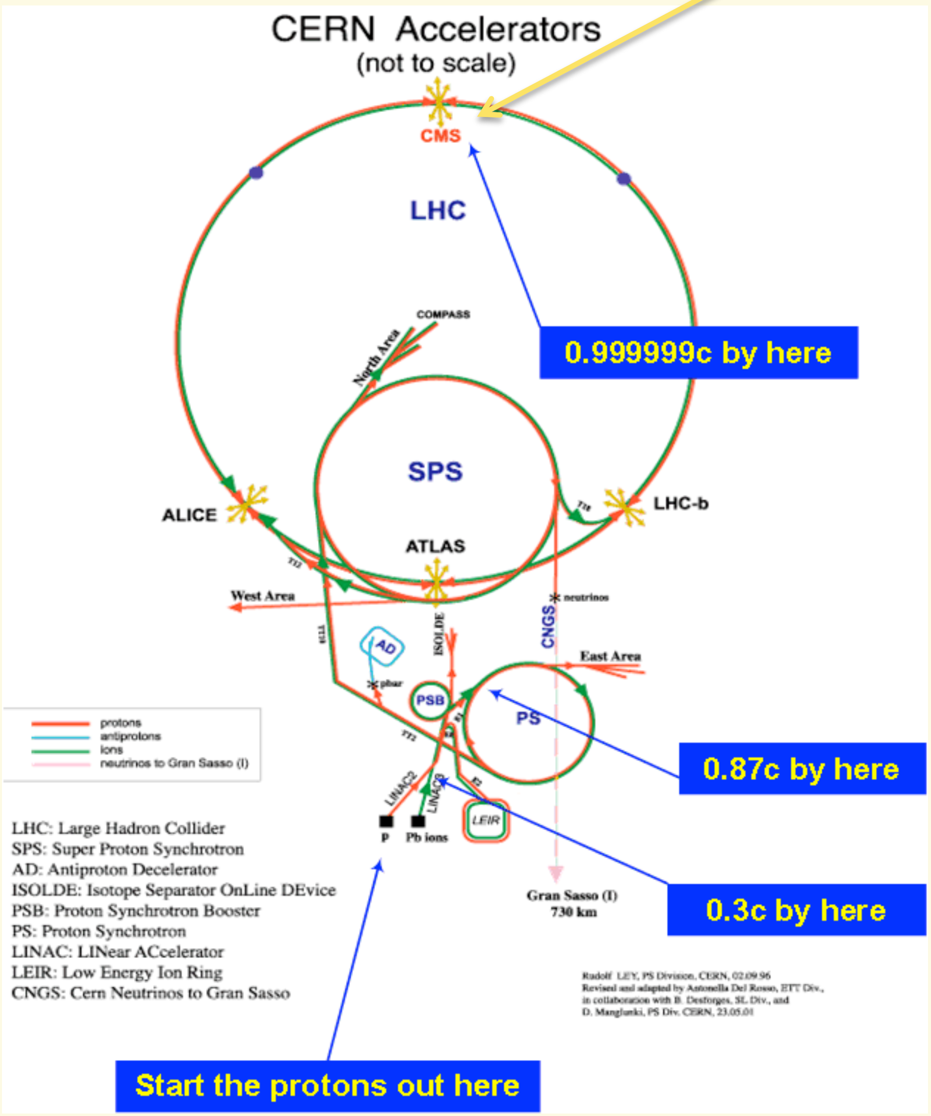
Works for MET too

JME-10-004

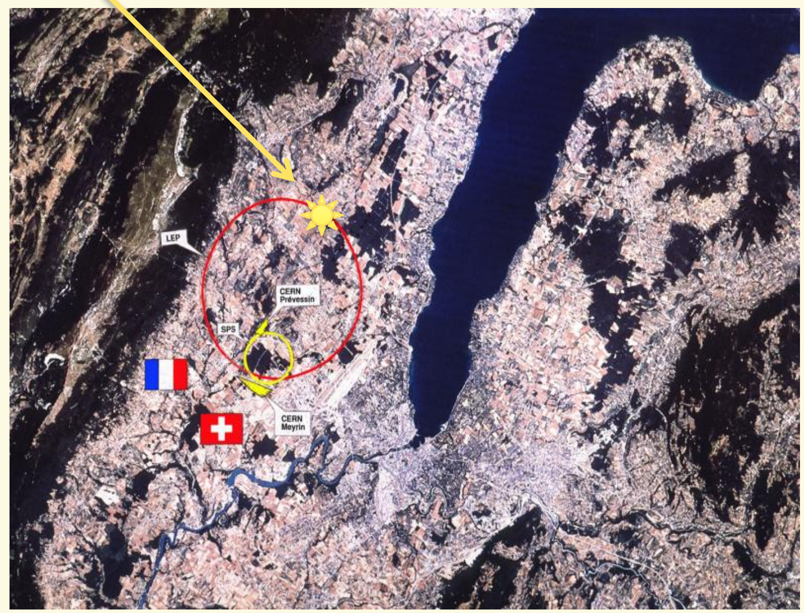


Won't work if significant signal with low jet multiplicity (as often occurs when significant squark-squark production)

CMS



CERN Accelerators
(not to scale)
CMS
LHC
0.999999c by here
COMPASS
North Area
SPS
ALICE
LHC-b
ATLAS
West Area
neutrinos
CNGS
ISOLDE
AD
pbar
East Area
PSB
PS
0.87c by here
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
LINAC2
LINAC3
P
Pb ions
LEIR
Gran Sasso (I)
730 km
0.3c by here
LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso
Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01
Start the protons out here



LEP
CERN Prévessin
SPS
CERN Meyrin